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Methodologies for Assessing the Cumulative Environmental Effects of Hydroelectric Development of Fish And Wildlife in the Columbia River Basin

Volume 1: Recommendations

Final Report 1987

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METHODOLOGIES FOR ASSESSING THE CUMULATIVE ENVIRONMENTAL EFFECTS OF HYDROELECTRIC DEVELOPMENT OF FISH AND WILDLIFE IN THE COLUMBIA RIVER BASIN

Volume 1: Recommendations

Final Report

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Methodologies for Assessing the Cumulative Environmental Effects of Hydroelectric Development on Fish and Wildlife in the Columbia River Basin

Volume 1: Recommendations

by

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ABSTRACT

This volume is the first of a two-part set addressing methods for assessing the cumulative effects of hydropower development on fish and wildlife in the Columbia River Basin. Species and habitats potentially affected by cumulative impacts are identified for the basin, and the most significant effects of hydropower development are presented. Then, current methods for measuring and assessing single-project effects are reviewed, followed by a review of methodologies with potential for use in assessing the cumulative effects associated with multiple projects. Finally, two new approaches for cumulative effects assessment are discussed in detail. Overall, this report identifies and reviews the concepts, factors, and methods necessary for understanding and conducting a cumulative effects assessment in the Columbia River Basin. Volume 2 will present a detailed procedural handbook for performing a cumulative assessment using the integrated tabular methodology introduced in this volume.

1 INTRODUCTION

The purpose of this document is to assist the Bonneville Power Administration (BPA) with its responsibilities under the Pacific Northwest Electric Power Planning and Conservation Act of 1980 (P.L. 96-501). This legislation led to the development of the Columbia River Basin Fish and Wildlife Program, under which BPA was requested to fund a study to develop criteria and methods for assessing the cumulative environmental effects of hydroelectric development. The Hydropower Assessment Steering Committee (HASC) of the Northwest Power Planning Council (NWPPC) outlined an approach to this study, which included seven tasks:

1. Identify species and habitats that are cumulatively affected by hydroelectric development,

2. Identify the types of environmental effects associated with hydroelectric developments,

3. Identify the interactions among hydroelectric development and other activities in the river basin,

4. Describe existing assessment techniques for use in cumulative effects assessment,

5. Evaluate the applicability of existing assessment methodologies to the Columbia River Basin,

6. Develop a stock/recruitment model as a cumulative effects indicator, and

7. Recommend two cumulative effects assessment methodologies for use in the Columbia River Basin.

This document is structured according to the tasks outlined above. The key species and habitats that can be affected by hydropower development and operation are discussed in Sec. 2. Section 3 discusses the important or most common hydropower effects that have been documented for fish and wildlife in the Pacific Northwest. The focus in that section is on single-project effects. The methods most commonly used to measure and assess these single-project effects on fish and wildlife populations and habitats are then discussed in detail in Sec. 4. Section 5 discusses the concepts necessary for understanding and assessing cumulative effects in the Columbia River Basin. Existing assessment methodologies that either have been used for the assessment of cumulative effects or could be modified for this purpose are reviewed in Sec. 6. Stock/recruitment models and their applicability to cumulative assessment are presented in Sec. 7, along with an in-depth discussion of a new approach to cumulative assessment -- the integrated tabular methodology.

The broad scope of this document makes it possible only to provide a general understanding of the issues involved in cumulative effects assessment and to identify those of greatest importance to the Columbia River Basin. As a consequence, some detailed information may be only cursorily treated or omitted. This document is not intended to describe a procedure for the successful completion of a cumulative effects assessment. Such a procedure will be dicussed in the second volume of this report. Volume 2 will include an example of small hydroelectric development in a hypothetical river basin, an assessment of the cumulative effects of the developments, and procedural guidelines for cumulative effects assessment.

2 KEY SPECIES AND HABITATS IN THE COLUMBIA RIVER BASIN

2.1 INTRODUCTION

Many fish and wildlife species and the habitats in which they live are affected by the construction and operation of hydroelectric facilities. This section lists those species and habitats that are most likely to be the focus of cumulative effects assessment for hydroelectric development.

The HASC recommended that a list of no more than 30 species and 15 habitats be developed. To aid in this process,HASC developed an initial list for consideration (Table 2.1). This list distinguishes some subspecies of salmon but combines some resident-fish species **and** wildlife species into groups. The HASC specified that additions to or deletions from this list be made based on the degree of societal concern for a species. This is reflected by established agency management plans and ecological interest and by the degree of documented evidence of hydropower impacts on the species.

2.2 FINAL LIST OF SPECIES AND HABITATS

A final list of fish and wildlife species potentially affected in a cumulative manner in the Columbia River Basin was developed from the HASC list. It was developed

TABLE 2.1 HASC List of Key Fish and Wildlife Species and Habitats of Concern in the Columbia River Basin

Anadromous fish	Wildlife
Spring chinook salmon	Big game
Summer chinook salmon	Up1 and game
Fall chinook salmon	Waterfowl
Summer steelhead trout	Raptors
Winter steelhead trout	Furbearers
Sea-run cutthroat trout	
Sockeye salmon	
Coho salmon	Habitats
	Riparian habitats
Resident fish	Spawning areas for fish
	Rearing areas for fish
Westslope cutthroat trout	Denning areas for wildlife
Warmwater game fish	Migration areas for wildlife
Migratory resident trout	Wetlands
Kokanee salmon	Migration areas for fish
White sturgeon	Wintering areas for wildlife

after a search of the literature to determine impact significance. Species were included on this list if one or more of the following three criteria applied (see Tables 2.2 and 2.3): (1) the catch or harvest of the species is specifically managed or regulated by a Federal or state agency, (2) the species is designated as threatened or endangered by a state or the Federal government, and (3) the occurrence of the impact on the species is documented in the literature and the impact is regarded in the literature as serious or significant. Some additional wildlife species that did not meet the above criteria were included if hydropower development in the Columbia River Basin has been or could be a significant factor in their abundance or distribution. Section 3 provides documentation of the effects of hydropower development on species and habitats of fish and wildlife.

The habitats of concern in HASC's initial list included those most often affected by hydropower development, such as streams, riparian areas, and wetlands. Critical areas used by fish and wildlife (e.g., spawning, wintering, and migration areas) were also included. The physical changes in the environment induced by hydropower development affect fish and wildlife species either by directly causing mortality or by affecting their ecological requirements in some way. These ecological requirements are met by the habitats in which the species live and the fulfillment of these requirements is dependent on habitat characteristics related to habitat quality. Certain critical requirements of a species may only be met in a relatively limited geographical area. These locations can become traditional use areas (e.g., roosts, wintering areas, mineral licks, migration routes) for a relatively large segment of the regional population. Hydropower development in these locations can have disproportionately large impacts.

The final list of habitats affected by hydropower development in the Columbia River Basin includes stream habitats, riparian habitats, wetlands, and old-growth forest. The ecological requirements of fish that should be considered in assessing hydropower effects relate to (1) reproduction, i.e., spawning and nesting, (2) rearing, and (3) migration; those for assessing effects on wildlife relate to (1) feeding, (2) movement, including migration and daily travel, (3) reproduction, including nesting and fawning, and (4) shelter.

TABLE 2.2 Final List of Fish Species Affected by Hydroelectric Development in the Columbia River Basin

	Criteria for Inclusion		
Species on the Final List	State or Federal Management	Threatened or Endangered Status	Literature Documentation
Migratory fish			
Anadromous salmonids			
Spring chinook salmon	X	-	X
Summer chinook salmon	X	-	X
Fall chinook salmon	X	-	X
Coho salmon	X	-	X
Pink salmon	X	-	X
Sockeye salmon	X	-	X
Chum salmon	X	-	X
Winter steelhead trout	X	-	X
Summer steelhead trout	X	-	X
Sea-run cutthroat trout	X	-	X
Other migratory fish			
Kokanee salmon	X	-	X
Bull trout	X	-	X
White sturgeon	X	-	X
American shad	X	-	X
Resident fish			
Resident salmonids			
Cutthroat trout	X	-	X
Rainbow trout	X	-	X
Brown trout	X	-	X
Dolly Varden trout	X	-	X
Brook trout	X	-	X
Mountain whitefish	X	-	
Other resident fish			
Bullheads (spp.)	X	-	X
Channel catfish	X	-	X
Burbot	X	-	X
Largemouth bass	X	-	X
Smallmouth bass	X	-	X
Sunfish (spp.)	X	-	X
Crappie (spp.)	X	-	X
Walleye	X	-	X
Yellow perch	X	-	X

TABLE 2.3 Final List of Wildlife Species Affected by Hydroelectric Development in the Columbia River Basin

Species on the Final List	Criteria for Inclusion		
	State or Federal Management	Threatened or Endangered Status	Literature Documentation
<u>Water birds</u>			
Canada goose	X	-	
Mallard	X	-	
Teal (spp.)	X	-	
Wood duck	X	-	
Ring-necked duck	X	-	
Goldeneye	X	-	
Hooded merganser	X	-	
Great blue heron	X	-	
California gull	X	-	
Ring-billed gull	X	-	
Forster's tern	X	-	
Caspian tern	X	-	
Kingfisher[a]		-	
Dipper[a]		-	
<u>Birds of prey</u>			
Red-tailed hawk	X	-	
Bald eagle	X	X	
Osprey	X	-	
Peregrine falcon	X	X	
Long-eared owl[a]		-	
Spotted owl	X	X	
<u>Upland game birds</u>			
Grouse (spp.)	X	-	
Quail (spp.)	X	-	
Partridge (spp.)	X	-	
Ring-necked pheasant	X	-	
Mourning dove[a]		-	
<u>Nongame land birds</u>			
Yellow-bellied sapsucker[a]		-	
Downy woodpecker[a]		-	

TABLE 2.3 (Cont'd)

Species on the Final List	Criteria for Inclusion: State or Federal Management	Threatened or Endangered Status	Literature Documentation
Large carnivores			
Grizzly bear	X	X	
Black bear[a]	X		
Gray wolf	X	X	
Bobcat[a]	X		
Semiaquatic furbearers			
River otter	X	-	X
Mink	X	-	X
Muskrat	X	-	X
Beaver	X	-	X
Small game			
Mountain cottontail	X		
Big game			
Elk	X		X
Moose	X		
Mule deer	X		X
White-tailed deer	X	X	X

[a]Added based on the opinion of the authors or professional resource managers, although the formal criteria did not specifically apply.

3 EFFECTS OF HYDROELECTRIC DEVELOPMENT ON FISH AND WILDLIFE SPECIES IN THE COLUMBIA RIVER BASIN

3.1 INTRODUCTION

The effects of hydroelectric development on populations of fish and wildlife have been discussed and documented in numerous published reports. Although many of the details remain unknown, a broad picture of how hydropower effects are generated and how populations respond to them has emerged. This section discusses the major effects directly or indirectly caused by hydroelectric development. The four major hydropower activities (construction, operations, maintenance, and abandonment) were recategorized into six hydropower actions, based on the impacts which the actions produce. Construction actions are construction of project facilities, dam placement, and stream impoundment. Operations and maintenance actions are dam operations, water diversion, and impact mitigation. The discussion of the effects of these actions focuses on project-specific effects without consideration of the important interactions with other hydropower development sites or with other types of development and human activities. The ways in which these interactions can produce cumulative effects are discussed in Sec. 5.

The HASC provided a list of the common effects of hydroelectric development on fish and wildlife. This list was used as the basis for the list of hydropower effects considered in this report. The hydropower effects considered are presented in Tables 3.1 and 3.2 for fish and wildlife, respectively, together with the hydropower action that produces the effect. No items from the HASC list were dropped; however, some effects were combined, and several more were added on the basis of literature documentation or agency comment. Overharvest of wild stocks in a multiple-stock fishery was added to the list of effects on fish. Increased human access and disturbance, bird mortality at distribution and transmission lines, and reduction in aquatic prey were added to the list of effects for wildlife.

The discussion of environmental effects on fish and wildlife in this section is based on information from published and unpublished literature. Commercial and public literature data bases, university libraries, and resource agency libraries were searched for relevant literature, and active investigators were asked to provide unpublished information. This section contains (1) a description of each hydropower effect and its origin, (2) identification of those species in the Columbia River Basin (from the complete list provided in See. 2) most likely to be affected, and (3) documentation.

3.2 DOCUMENTATION OF HYDROELECTRIC IMPACTS ON FISH

3.2.1 Sedimentation and Erosion

The construction of hydroelectric facilities involves earth-moving work in and around the stream being used. During construction, these areas are exposed to wind and water erosion, which can result in the release of sediment into stream waters.

TABLE 3.1 Impacts of Hydroelectric Development on Fish Species in the Columbia River Basin

Action	Impacts
Construction	Sedimentation and erosion Disturbance of hazardous waste and nutrient sinks
Diversion	Interference with fish migration Altered stream flow
Dam placement	Interference with fish migration Disruption of food production and transport Sedimentation and erosion
Water impoundment	Inundation of stream habitats Interference with fish migration Change in fishing area, opportunity, and catch Change in water quality
Dam operation	Interference with fish migration Sedimentation and erosion Altered stream flow
Impact mitigation efforts	Altered stream flow Overharvest of wild stocks Interference with fish migration

Construction of facilities frequently requires excavation and alteration of slopes, which can result in slope instability and failure, and the subsequent deposition of sediments into the stream. Typically, sedimentation resulting from construction activities occurs during and for several years after the construction period.

Increased water turbidity can also be produced by erosion of the shoreline and bed of the impoundment during hydroelectric generation, especially if a peaking mode of operation is used. Wide fluctuations in water level and flow rates prevent the stabilization of shoreline areas by littoral vegetation and encourage continued erosion and contribution of sediment to reservoir waters. Up to 100% of this sediment may be deposited within the impoundment because of the low current velocity within impounded reaches (Lara 1973). This is especially true for large reservoirs; small reservoirs may collect little of the stream's sediment load because of their low storage volume. Water released from large impoundments is typically clear and sediment-free due to deposition of the sediment in the reservoir.

Increased turbidity in stream and impoundment waters can adversely affect fish populations. Documented impacts of increased turbidity include increased egg mortality

TABLE 3.2 Impacts of Hydroelectric Development on Wildlife Species in the Columbia River Basin

Action	Impacts
Construction	Increased human access and disturbance Reduction in aquatic prey
Impoundment, diversion, and placement of project facilities	Loss of critical terrestrial habitats Loss of stream habitats Creation of open-water habitats Interruption of movement and migration Bird mortality at distribution and transmission lines Reduction in aquatic prey
Dam operation	Degradation of shoreline habitats Reduction in aquatic prey

(McNeil1 and Ahnell 1964, Reiser and White 1981, Sigler et al. 1984), decreased growth and production of juvenile fish (Crouse et al. 1981, Sigler et al. 1984), destruction of spawning habitats (McNeil1 and Ahnell 1964, Kaster and Jacobi 1978), and reduction in benthic invertebrates used as food (Kaster and Jacobi 1978).

Dam construction may significantly alter the downstream patterns of erosion and sedimentation with subsequent major changes in channel morphology, including the elimination of side channels (Petts 1979, 1980). This change is brought about by alterations in the natural flow regime and the trapping of gravels and other bed materials above the dam. The relatively sediment-free water that is released from large impoundments can rapidly erode bed and bank materials downstream (Leopold et al. 1964, Taylor 1978, Petts 1984). Immediately downstream of a dam, one of four changes in channel morphology can take place: (1) an increase in channel depth due to erosion of the channel bed, (2) a decrease in channel depth due to deposition of sediments from eroding banks, (3) a decrease in channel width due to redistribution of the bed materials, or (4) a decrease in channel width due to deposition of materials on the channel banks. Degradation of the main stream channel may affect tributary streams as well. The channel gradients of the lower reaches of the tributaries are, in effect, increased by the lowering of the main channel, and consequently, erosion of the tributary occurs until a new equilibrium status is attained (Taylor 1978).

Alterations in the transport of gravels and changes in stream morphology can have adverse effects on fish populations. Riffle areas in which benthic invertebrates are produced, gravel bars used as spawning areas, and backwaters used as rearing areas are all dependent on the natural pattern of deposition and erosion. Spawning beds can be eliminated below the dam because the gravel in the downstream reach is eventually transported further downstream or covered with sediment, and new gravel is not deposited in its place (Fraser 1972, Hubbel 1973).

3.2.2 Disturbance of Hazardous Waste and Nutrient Sinks

Dredging and the disposal of dredged material during the construction of hydroelectric facilities can potentially result in the release of soluble toxic substances, such as hydrogen sulfide, and the resuspension of particulate matter containing high concentrations of heavy metals and toxic organic compounds, such as polychlorinated biphenyls (PCBs) and pesticides (Loar et al. 1980). These same activities can result in the release of nutrient substances. Sediments and soils in the project area can become contaminated initially as a result of activities occurring in the general vicinity of the site or at points upstream in the watershed. Mining spoils may have elevated concentrations of heavy metals such as arsenic, lead, and mercury; the erosion of spoil piles or leakage from mines can produce contamination of the stream sediments. Accidental spills or the deliberate illegal dumping of organic contaminants, such as PCBs, can produce concentrations of these contaminants in the bottom sediments of streams or lakes. Production of agricultural chemicals and agricultural practices within the watershed can result in elevated concentrations of nutrients or organochlorine pesticides in bottom sediments.

The contaminants released by dredging activities can have pronounced biological effects, depending on the concentration of the contaminant, its chemical form, and the length of time for which organisms are exposed. Releases of nutrient substances may result in lowered dissolved oxygen content of waters due to increased biological productivity. Acute toxicity to fish, and subsequent mortality, can occur if high concentrations of toxic contaminants are present in the water for a short period of time (i.e., days). Chronic toxicity can result if fish are exposed to low concentrations for longer periods (i.e., weeks). Although chronic toxicity often does not cause the immediate death of exposed individuals, increased physiological stress, increased susceptibility to disease, reduced growth, and reduced reproduction may result. In addition, some toxic substances can accumulate in the invertebrates that are eaten by fish. Fish may therefore be exposed to higher concentrations of the toxicant than are present in the water and for longer periods of time. These contaminants may also accumulate in the body tissues of exposed fish.

3.2.3 Interference with Fish Migration

Hydroelectric facilities can adversely affect migrating fish in several ways. Hydroelectric facilities may act as a total or partial block to the upstream migration of anadromous fish. Fish passing through hydroelectric facilities (i.e., turbines, spillways, or dam passage structures) can be killed during passage or suffer increased levels of stress and disease. Fish migrating downstream may experience delays in migration and increased predation.

When hydroelectric facilities, such as dams or diversions, block access to upstream reaches, this segment of stream habitat is lost to migratory fishes (Smoker 1953, Kraft 1968, White et al. 1981). In the Pacific Northwest, high dams have effectively blocked access to hundreds of miles of spawning areas (Fowler 1978). Over 50% of the Columbia River Basin is currently blocked to anadromous fish as a result of hydroelectric development (Ward and Stanford 1979b). Even a temporary blockage of the stream, as may occur during construction, can eliminate an anadromous fish population if the population does not spend much time at sea before returning to spawn (Baxter 1977).

The downstream migration of anadromous fish can be delayed by hydroelectric facilities because of the slower current velocities in the impoundment, passage through the turbines and bypass facilities, and the reduced discharge below the facility. Migration times that are more than double those recorded before hydroelectric development have been documented for salmon in the Columbia River Basin (Bentley and Raymond 1976, Raymond 1979). Migration delays can increase the exposure of juveniles to predators, gas supersaturation effects, higher water temperatures, and disease. Delays can become critical for many anadromous fish if prolonged beyond the physiologically determined period of transformation from a freshwater to saltwater habitat (i.e., smoltification). Significant delays can cause a portion of the seaward run of juveniles to hold over in the reservoir or lower stream reaches and remain in the river as resident fish (Raymond 1968, 1969, 1979, Dunn 1975, Bentley and Raymond 1976, Dodge 1982, Ebel 1982).

Hydroelectric development can increase mortality rates in anadromous fish populations. Discrepancies in fish counts at successive dams on the Columbia River have indicated cumulative losses of trout and salmon that are as high as 40% on some runs (Trefethen 1972). Hydroelectric facilities restrict the migratory movements of fish and force passage through turbines, diversions, spillways, or bypass structures where the likelihood of injury and death is increased (Schoeneman and Junge 1954, Schoeneman, Pressey, and Junge 1961, Bell et al. 1967, Junge 1971, Dunn 1975, Long et al. 1975, Ebel 1977, Gibson et al. 1979, Stockley 1981). Bypass structures that are intended to reduce turbine passage are usually only partially effective and the mortality caused by turbine passage can increase overall mortality rates by 10% to 25% (Turbak et al. 1980). Fish passing through bypass structures experience stress (Congleton et al. 1984) and are exposed to a variety of infectious diseases (Horner and Bjornn 198la, b, and c).

Fish that are stunned, disoriented, or injured as they pass over or through hydroelectric facilities are vulnerable to the predators that concentrate in the tailrace of spillway discharge areas (Holden 1979, Mullan 1980, Turbak et al. 1980). Impoundments may provide favorable conditions for populations of piscivorous fish species that feed on juvenile migratory fish (Hamilton et al. 1970, Raymond 1979). The vulnerability of these fish to predation may be increased by high surface temperatures, low flows, and low turbidity (Bentley and Dawley 1981).

3.2.4 Altered Stream Flow

Hydroelectric development can produce alterations in natural stream flow that are detrimental to fish. The discharge of water from project facilities may be reduced or eliminated downstream as water is impounded or diverted. Impoundment can eliminate the natural flood regime of the stream. If a peaking mode of electricity generation is used, rapid changes in discharge occur that produce erratic stream flow conditions. (Some of the consequences of altered stream flow are addressed in Secs. 3.2.1, 3.2.3, 3.2.5, 3.2.7, and 3.2.8.)

Small-scale hydroelectric projects frequently employ diversion structures that produce at least some degree of stream dewatering immediately below the dam. Dewatered stream segments may be quite long, depending on the project configuration. Stream habitats that are affected by the diversion may be critical to fish populations in the stream and their alteration or elimination by dewatering can have significant impacts (Peters 1982). For example, a proposed diversion of Howell Creek in Montana could eliminate 18% of the bull trout spawning habitats in the North Fork Flathead River drainage area (Fraley et al. 1981). Dewatering may strand fish in pools where (1) physiological tolerances of adult and juvenile fish are exceeded (Canadian Department of Fisheries and Oceans 1984), (2) predation on juvenile fish is increased (Neel 1966), and (3) the diversity and abundance **of** benthic prey insects upon which juveniles depend is reduced (Trotzky and Gregory 1974).

Decreases in the amplitude and duration of naturally occurring seasonal floods can adversely affect fish downstream of hydroelectric facilities because floods can benefit fish populations by flushing sediments that normally accumulate in areas of low current velocity. The loss of sediment-free spawning areas for chinook salmon in the Trinity River in California has been attributed to this factor (Fraser 1972).

In contrast to natural floods, artificially produced fluctuations in water levels can have serious adverse effects on fish populations. Wide fluctuations in current velocity and depth can cause changes in erosion, sedimentation, and channel morphology. Sudden decreases in flow can cause reductions in the productivity of aquatic plants and benthic invertebrates important to fish (Kroger 1973). Decreases and fluctuations in flow can impede migration, strand fish (Bauersfeld 1977, 1978b, Stanford and Ward 1979, Becker et al. 1981, Stober et al. 1982), adversely affect reproduction (Fraser 1972, Kraft 1972, Peters 1982), and cause shifts in habitat use as fish move to areas with preferred current velocities (Canadian Department of Fisheries and Oceans 1984, Neel 1966). Impacts of flow fluctuations on fish eggs can also occur and include stranding (Thompson 1978, Stober et al. 1977, Bauersfeid 1978a, Graybill et al. 1979, Stanford and Ward 1979, Becker et al. 1981, Edwards, Krieger, Bactelles, and Maugham 1982, Edwards, Krieger, Gebhart, and Maugham 1982, Stuber et al. 1982, Beam 1983), desiccation, freezing, sedimentation, low oxygen concentrations, and mechanical damage due to the settling of gravel (Reiser and White 1981, 1983).

3.2.5 Disruption of Food Production and Transport

Hydroelectric dams can block the upstream and downstream movements of stream invertebrates and lead to changes in the species composition and productivity of these organisms (Ward and Stanford 1979a). These changes can adversely affect fish because stream invertebrates are important sources of food for many species. However, in some cases, large reservoirs can contribute food organisms that are produced within the impoundment (e.g., zooplankton, larval fish) and therefore supplement downstream food availability. The impact of a dam on food production and transport is highly dependent on the size of the dam; significant impacts are generally limited to large dams. Other hydroelectric impacts on fish food organisms are presented in Secs. 3.2.1, 3.2.4, and 3.2.8.

3.2.6 Inundation of Stream Habitats

Hydroelectric development usually requires the impoundment of some stream waters. The length of the impounded section of stream depends on the design capacity of the project (i.e., the necessary hydraulic head) and the local topography. Streams provide essential habitats for many fish species, including the anadromous species of the Pacific Northwest. Streams also provide ideal conditions for production of the benthic invertebrates used as food by anadromous species and also provide important spawning and rearing areas for these fish. Inundation may render impounded stream reaches unsuitable for spawning because moving water is necessary for proper embryonic development (Mains 1977). The creation of impoundments can favor some resident fish.

3.2.7 Changes in Fishing Area, Opportunity, and Catch

The development of hydroelectric facilities may affect the type and availability of fishery resources in the project area and associated waters. Some commercially valuable fish populations, especially those of anadromous fish, may be reduced or eliminated as a consequence of several factors, including barriers to migration, turbine-caused mortality, loss or degradation of suitable habitats, and changes in water quality. The elimination of runs of anadromous fish and changes in downstream riverine habitats may result in the proliferation of fish species not normally abundant in the stream. Impoundments may also cause new fisheries to develop that differ from the former stream fisheries in species and catch rates. Impoundments may induce residualism, which produces a nonmigratory population of fish in reservoirs. Outplanted smolts may also provide a fishery in streams above a reservoir. Change in fishery species and catch rates also occurs when species that prefer or can tolerate lentic waters (e.g., warm-water resident fish) replace those species that do not (e.g., anadromous species) (Holden 1979, Petts 1984). These changes in species composition can occur rapidly or over a period of years. Small-scale hydroelectric projects, however, typically do not have impoundments that are large enough to sustain a lake fishery and may simply lead to the elimination of fisheries dependent on anadromous species. Fishing opportunities may also be affected by changes in access to the stream; access by fishermen may be either reduced or enhanced as a consequence of the placement of hydroelectric facilities.

3.2.8 Changes in Water Quality

Hydroelectric development can have direct impacts on water quality, especially if fairly large impoundments are created. Reservoir discharge may differ from natural stream water in many physicochemical characteristics. The discharge of this water from the impoundment can strongly influence the quality of water downstream (Neel 1966). The major water quality impacts identified for the Columbia River Basin include impacts on water temperature, dissolved gases (oxygen and nitrogen), nutrient transport, and turbidity. The effects of turbidity on fish are discussed separately in Sec. 3.2.1.

Any change in natural stream temperatures or thermal cycles can have direct and indirect effects on fish populations downstream of hydroelectric facilities. Generally, deep water withdrawals from large reservoirs reduce the natural variation in temperature by moderating summer high and winter low temperatures (Neel 1966). These changes can be detrimental to downstream fish populations by interfering with the timing of hatching and migration (Ingram and Korn 1969, Geen 1974, Graybill et al. 1979, Canadian Department of Fisheries and Oceans 1984, Zakel and Reed 1984). In addition, reduced seasonal variation in downstream temperatures can reduce the production of benthic invertebrates by interfering with critical thermal requirements (Geen 1974, Lehmkuhl 1972, 1979). Small reservoirs that do not stratify or reservoirs with surface water withdrawals can produce elevations in downstream temperatures. Elevated maximum temperatures can induce direct stress on cold-water fish species when maximum water temperatures exceed tolerance limits for short periods (e.g., days or parts of days) or exceed optimum conditions for long periods (e.g., weeks or months) (Brett 1952, Ingram and Korn 1969).

Air and water can be mixed and carried to substantial depths in the plunge basin of spillways. Hydrostatic pressures are often sufficient within the plunge basin to greatly increase the solubilities of atmospheric gases and produce nitrogen supersaturation of the water (Weitkamp and Katz 1980). Fish living in supersaturated waters can develop elevated concentrations of nitrogen in their blood, a condition that produces gas bubble disease (Beiningen and Ebel 1970, Fickeisen and Schneider 1976). The susceptibility of fish to the development of gas bubble disease varies among species and life stages (reviewed in Bouck 1980, Weitkamp and Katz 1980); both juvenile and adult salmonids are known to be susceptible (Ebel et al. 1975, Stockley 1975). On the Columbia River, supersaturation of the water increases from one dam to the next and can produce severe losses of salmon and steelhead, especially in years of high flow (Ebel and Raymond 1976, Diamond and Pribble 1978).

Low concentrations of dissolved oxygen can develop during the summer in the cold bottom waters of large-scale hydroelectric impoundments. The release of these anoxic waters can depress dissolved oxygen levels downstream and adversely affect fish. The physical and chemical processes leading to dissolved oxygen impacts downstream of reservoirs have been documented in a number of cases (e.g., Ebel and Koski 1968, Hannan 1979).

Large reservoirs can act as nutrient sinks and alter nutrient transport to downstream areas because of concentration and deposition of nutrients by sediments and organic matter from macrophytic and planktonic production. The trapping of nutrients may reduce downstream biological productivity and eventually affect fish productivity (Coon et al. 1977). Reservoir nutrient retention has not been well documented except in a few cases involving large reservoirs.

3.2.9 Overharvest of Wild Stocks in Mixed-Stock Fisheries

Streams and impoundments are frequently stocked with fish to mitigate the adverse effects of hydroelectric development on the native fish population. Although hatchery supplementation or stocking may counteract the decline in the total number of fish that results from hydroelectric development, the original wild stocks of fish may be adversely affected. Introduced stocks may differ from wild stocks in various ways, including growth rates, reproductive rates, and the timing of spawning. These differences may produce greater catchability for wild stocks so that, in a mixed-stock fishery where catch limits are set for the total run, mortality of wild stocks may be very high. If the fishery is not managed on a stock-by-stock basis, these differences could potentially lead to the differential overharvest and elimination of wild stocks from the stream (Ricker 1975). The population size of wild stocks may be much smaller than that of introduced stocks. If wild and introduced stocks are not reproductively isolated from each other, the differences in the number of individuals could lead to the eventual disappearance of wild characteristics, as genes from introduced stocks become numerically dominant in the gene pool.

3.3 DOCUMENTATION OF HYDROELECTRIC IMPACTS ON WILDLIFE

3.3.1 Increased Human Access and Disturbance

The construction of hydroelectric facilities frequently leads to increased human access to relatively remote areas and to an increase in disturbance to wildlife (Rochester et al. 1984). The occurrence of humans and human activity within an animal's home range can cause the resident to avoid or abandon that range and the surrounding areas. The adverse effect of increased human activity has been documented for a variety of species, including bald eagles (Stalmaster and Newman 1978, Fitzner et al. 1980, Grubb 1980, Hansen et al. 1980, Skagen 1980, Stalmaster 1980, Garcia et al. 1983, Knight and Knight 1984), osprey (Levenson and Koplin 1984), gulls (Garcia et al. 1983), green-backed herons (Kaiser and Fritzell 1984), mountain goats (Foster and Rahs 1983), elk (Edge and Marcum 1985), and mule deer (Freddy et al. 1986). Construction noise alone (e.g., blasting, heavy equipment operation) can trigger abandonment of the affected area by sensitive species. For example, mountain lions avoid recently logged areas and areas with even minimal human activity (Van Dyke et al. 1986).

Harassment of wildlife, especially large species, can be **a** problem at construction sites and can result in abandonment of the area or injury to individual animals (Moore and Mills 1977). Harassment has a greater impact when animals are already under physiological stress due to, for instance, winter conditions, reproduction, or food shortage.

The presence of new access roads can encourage recreational use of otherwise neglected areas and result in an increase in harassment and legal and illegal hunting pressure (Canadian Department of the Environment 1981). Any increase in the use of access roads by motorized vehicles also increases the probability of collisions with wildlife. For example, the development of roads and railways paralleling reservoirs of the lower Snake River poses a significant danger to wildlife trying to access riparian habitats (U.S. Army Corps of Engineers 1975).

3.3.2 Reduction in Aquatic Prey

All phases of hydroelectric development (construction, impoundment, diversion, and operation) can interact to bring about a reduction in the abundance of aquatic prey.

This can cause adverse impacts to fish-eating wildlife species. The impacts of hydroelectric development on fish were discussed in detail in Sec. 3.2.1. Wildlife species of concern within the Columbia River Basin that could be adversely affected by a reduction in aquatic prey include hooded mergansers, kingfishers, great blue herons, dippers, bald eagles, ospreys, grizzly bears, river otters, and mink.

3.3.3 Loss of Critical Terrestrial Habitats

The impoundment of a stream invariably floods and destroys terrestrial habitats upstream of the dam site. Most often, the impounded areas are within the floodplain of the stream and include riparian and island habitats that receive disproportionately heavy use by wildlife species for feeding, reproduction, and shelter (Best et al. 1979, Odum 1979, Samson 1979, Knopf 1985). In addition, the creation of rights-of-way for electrical distribution lines associated with hydropower facilities also causes habitat loss. Flooding and right-of-way development usually results in the mortality of small, less-mobile vertebrates. Although larger vertebrates are able to leave the impact area, the displaced individuals may have reduced chances of survival in the surrounding area, especially if the population is at or near carrying capacity (Trefethen 1973).

In the Pacific Northwest, reservoir development has resulted in a substantial loss of diverse productive wildlife habitats (Oliver 1974, Nelson et al. 1976, Bedrossian et al. 1984, Montana Department of Fish, Wildlife, and Parks 1984a, 1984b, Oregon Department of Energy 1983, Wood and Olsen 1984a, 1984b). Some individual large-scale projects have caused significant losses. For example, bird use of one area of the Snake River in southeastern Washington declined by nearly 14,000 birds during the summer and 30,000 birds during the winter as a result of impoundment (Lewke and Buss 1977).

Impoundment and the placement of project-related facilities such as access roads, buildings, diversion structures, and power corridors can also result in the loss of other critical wildlife habitats, including nonriparian wetlands (e.g., marshes, bogs), old-growth forest, and local high-use areas (e.g., rookeries, roosts, wintering areas). Impacts to these areas can be significant because these areas typically receive a great deal of use by a relatively large percentage of the regional wildlife. A hydroelectric facility in British Columbia flooded about 33 hectares of land that provided 10% of the white-tailed deer population’s winter range (Woods and Bradley 1979). Reservoir development along the Columbia River resulted in the loss of fire-free islands that are important foraging areas for white-tailed deer in the region (U.S. Fish and Wildlife Service 1980, Garcia et al. 1983).

Downstream impacts of impoundment can also affect wildlife. Riparian vegetation is dependent on the natural flooding regime of the stream (Odum 1979, Petts 1984). Impoundment usually eliminates this flooding regime below the dam and thus allows the encroachment of upland vegetation within the normal floodplain (Baxter 1977). Nonriparian wetlands dependent on stream flow may be adversely affected by reductions in flow below a dam (Johnston et al. 1981). These areas may become less attractive to many species of wildlife that normally use them.

3.3.4 Loss of Stream Habitats and Creation of Open-Water Habitats

Hydroelectric development usually involves the loss of stream habitats and the creation of at least some open-water habitats as stream waters are impounded behind a dam. Projects involving diversion of stream waters may dewater large segments of the stream without creating open-water habitats. Stream habitats are especially valuable to mallards, wood ducks, hooded mergansers, bald eagles, osprey, kingfishers, dippers, grizzly bears, and semiaquatic furbearers in the Columbia River Basin. These species use stream habitats primarily as feeding areas and may be adversely affected by stream loss.

Some species may benefit from the creation of large open bodies of water because of an increase in food supply (e.g., warm-water fish, aquatic macrophytes). These species include osprey, mink, muskrat, and most of the waterbirds listed in Sec. 2 except kingfisher and dipper. In the Pacific Northwest, osprey numbers have increased, apparently as a result of the creation of large reservoirs (Roberts and Lind 1977, Henny et al. 1978, Bedrossian et al. 1984, Montana Department of Fish, Wildlife, and Parks 1984a, 1984b, Wood and Olsen 1984a, 1984b).

The value of an impoundment to wildlife depends on certain conditions, including the local topography, stability of water levels, and size of the impoundment (Trefethen 1973, Williams 1985). Steeply sloping shorelines and wide fluctuations in water level prevent the establishment of plants in the littoral zone and reduce fish productivity. Impoundments with these characteristics are of limited value to wildlife. Many small-scale hydropower projects have impoundments that are small, are in areas of steep topography, and have greatly fluctuating water levels during periods of power generation (Rochester et al. 1984).

The value of an impoundment to wildlife often declines with the age of the impoundment as succession results in replacement of favored aquatic food plants with less preferred species (Kadlec 1962, Rakstad and Probst 1985). This decline can only be prevented by management of the impoundment for wildlife -- a goal that is often at odds with hydroelectric generation goals.

3.3.5 Interruption of Movement and Migration

Hydroelectric facilities (i.e., impoundments, diversion canals, and penstocks) can sometimes form a barrier to movement for large mammals (Nelson et al. 1976, Parker 1976, Heinzenknecht and Paterson 1978, Klingeman 1981, Adams 1982, Fletcher 1983, Oregon Department of Energy 1983). Animals attempting to cross open diversion canals can drown because they can enter the canal but have difficulty escaping due to the smooth sides of the canal (Guenther et al. 1979, Horak and Olsen 1981, Oregon Department of Energy 1983). Blockage of movement or migration is especially important if the project incorporates a large reservoir or aboveground diversion structures of great length. In order for a barrier to have a regionwide effect on wildlife, the barrier must block or restrict traditional wildlife migration routes or travel corridors. The migratory mammals in the Columbia River Basin that are most likely to be affected by hydroelectric development are elk and mule deer. Populations of these species often spend the summer at high elevations and the winter at lower elevations. Migration routes frequently follow natural drainages and thus bring these species into direct conflict with hydropower development. Blockage of established travel corridors may be important if these corridors lead to important use areas (e.g., mineral licks, den sites).

3.3.6 Bird Mortality at Distribution and Transmission Lines

Electrical power produced by a hydroelectric generating facility is often transmitted from the project site to the power transmission grid via aboveground distribution lines. Both distribution and transmission lines can result in mortality if birds collide with or land on the lines and are electrocuted (see the annotated bibliography provided by Avery et al. 1978). Electrocution can occur if two conductors, or a conductor and a ground wire, are contacted simultaneously. The probability of collision and electrocution can be higher in areas with hydroelectric development than in other areas because many birds concentrate their activities near streams and wetlands and because many small-scale hydropower projects are located in remote areas and require long distribution lines (Rochester et al. 1984).

The design characteristics of distribution and transmission lines can affect the probability of collision and electrocution (Thompson 1978, Rochester et al. 1984). Collision is more likely if the lines are higher than surrounding objects such as trees and bluffs. Larger, more visible lines can be avoided in flight but small lines (such as ground wires) may not be seen in time to prevent collision. Lines in dense vertical arrays are more likely to be hit than are lines on a single level. Electrocution can be prevented by putting lines far enough apart to make simultaneous contact impossible.

Although line collisions and electrocution contribute a very small percentage to overall bird mortality (approximately O.l%, according to Thompson 1978), some species populations (e.g., protected species) cannot tolerate any increase in mortality. All of the bird species of concern in the Columbia River Basin may be affected by the increased potential of collision (Anderson 1978, Garcia et al. 1983, Oregon Department of Energy 1983), although the most frequent victims seem to be large migratory water birds (Thompson 1978). Raptors, especially ospreys and bald eagles, are most likely to experience increased incidences of electrocution because they have a large wingspan and may perch on lines and frequently nest on poles or towers in open country.

3.3.7 Degradation of Shoreline Habitats

Hydroelectric power is usually generated using peaking or run-of-river operations. Peaking operations involve the periodic impoundment of water behind a dam followed by release of the water through turbines to generate electricity. Peaking operations are frequently used in low-gradient streams. Run-of-river operations are typically used on higher-gradient streams and involve the diversion of flowing water through a penstock (Rochester et al. 1984). Little or no impoundment of water is required for run-of-river operations.

Peaking operations (but generally not run-of-river operations) result in fluctuations in water level both below and above the dam. These fluctuating water levels can result in the deterioration of shoreline habitats that are important for certain wildlife species. Aquatic macrophytes that grow in the shallow water near shore are generally not tolerant of widely fluctuating water levels (Penfound 1953, Young 1973). These plants are important sources of food and cover for many of the waterbirds and semiaquatic furbearers in the Columbia River Basin. Muskrat, beaver, mink, and river otter typically have dens in shoreline banks. Water-level fluctuations can make these dens unsuitable for use (Donohoe 1966, Slough and Sadleir 1977, McDonnell and Gilbert 1981, Brooks and Dodge 1981, 1986). Shoreline-nesting waterbirds could also be adversely impacted by fluctuating water levels because nests could be periodically submerged (Gregory and Mackey 1983).

3.4 SUMMARY

The construction and operation of hydroelectric facilities result in 16 broad categories of environmental effects on fish and wildlife: nine for fish and seven for wildlife (Tables 3.3 and 3.4). Given this number of categories, no cumulative effects assessment methodology that is designed to address only one effect or that deals with only one species will be adequate for the purposes of the Columbia River Basin Fish and Wildlife Program. Rather, the methodology should be capable of incorporating several effects or several species. The methodology should also be equally applicable to both fish and wildlife.

3.5 REFERENCES

Adams, A.W. 1982. Migration. Pages 301-321 in J.W. Thomas and D.E. Towelli, eds., Elk of North America. Stackpole Books, Harrisburg, Penn.

Anderson, W.L. 1978. Waterfowl collisions with power lines at a coal-fired plant. Wildlife Society Bulletin 6:77-83.

Avery, M.L., P.F. Springer, and N.S. Dailey. 1978. Avian mortality at man-made structures: an annotated bibliography. FWS/OBS-78/58. U.S. Fish and Wildlife Service, Washington, D.C.

Bauersfeld, K. 1977. Effects of peaking (stranding) of Columbia River dams on juvenile anadromous fishes below the Dalles Dam, 1974 and 1975. Technical Report 31. Washington Department of Fisheries. 117 pages.

Bauersfeld, K. 1978. Stranding of juvenile salmon by flow reductions at Mayfield Dam on the Cowlitz River, 1976. Technical Report 36. Washington Department of Fisheries. 36 pages.

Baxter, R.M. 1977. Environmental effects of dams and impoundments. Annual Review of Ecology and Systematics 8:255-83.

TABLE 3.3 Potential Impacts of Hydroelectric Development on Fish Species in the Columbia River Basin

Species	Change in Fishing Area, Opportunity, and Catch	Sediment-ation and Erosion	Fish Migration Inter-ference	Changes in Water Quality	Inundation of Stream Habitats	Altered Stream Flow	Over-harvest of Wild Stocks	Disruption of Food Pro-duction and Transport	Disturbance of Nutrient and Hazardous Waste Sinks
Migratory fish									
Anadromous salmonids									
Spring chinook salmon	X	X	X	X	X	X	X	X	X
Summer chinook salmon	X	X	X	X	X	X	X	X	X
Fall chinook salmon	X	X	X	X	X	X	X	X	X
Coho salmon	X	X	X	X	X	X	-	X	X
Pink salmon	X	X	X	X	X	X	-	X	X
Sockeye salmon	X	X	X	X	X	X	-	X	X
Chum salmon	X	X	X	X	X	X	-	X	X
Winter steelhead trout	X	X	X	X	X	X	X	X	X
Summer steelhead trout	X	X	X	X	X	X	X	X	X
Sea-run cutthroat trout	X	X	X	X	X	X	-	X	X
Other migratory fish									
Kokanee salmon	X	X	X	X	X	X	-	X	X
Bull trout	X	X	X	X	X	X	-	X	X
White sturgeon	X	-	X	X	-	-	-	X	X
American shad	X	-	X	X	-	-	-	-	X

TABLE 3.3 (Cont'd)

Species	Change in Fishing Area, Opportunity, and Catch	Sediment-ation and Erosion	Fish Migration Inter-ference	Changes in Water Quality	Inundation of Stream Habitats	Altered Stream Flow	Over-harvest of Wild Stocks	Disruption of Food Pro-duction and Transport	Disturbance of Nutrient and Hazardous Waste Sinks
<u>Resident fish</u>									
Resident salmonids									
Cutthroat trout	X	X	-	X	X	X	-	X	X
Rainbow trout	X	X	-	X	X	X	-	X	X
Brown trout	X	X	-	X	X	X	-	X	X
Brook trout	X	X	-	X	X	X	-	X	X
Dolly Varden trout	X	X	-	X	X	X	-	X	X
Mountain whitefish	X	X	-	X	X	X	-	X	X
Other resident fish									
Bullheads (spp.)	X	-	-	-	-	X	-	X	X
Channel catfish	X	-	-	-	-	X	-	X	X
Burbot	X	-	-	-	-	X	-	X	X
Largemouth bass	X	-	-	-	-	X	-	X	X
Smallmouth bass	X	-	-	-	-	X	-	X	X
Sunfish (spp.)	X	-	-	-	-	X	-	X	X
Crappie (spp.)	X	-	-	-	-	X	-	X	X
Walleye	X	-	-	-	-	X	-	X	X
Yellow perch	X	-	-	-	-	X	-	X	X

TABLE 3.4 Potential Impacts of Hydroelectric Development on Wildlife Species in the Columbia River Basin

Species	Increased Access and Disturbance	Loss of Terrestrial Habitats	Loss of Stream Habitats and Creation of Open-Water Habitats	Interruption of Movement and Migration	Mortality at Transmission Lines	Reduction in Aquatic Prey	Degradation of Shoreline Habitats
Water birds							
Canada goose	X	X	X	-	X	-	X
Mallard	X	X	X	-	X	-	X
Teal (spp.)	X	X	X	-	X	-	X
Wood duck	X	X	X	-	X	-	X
Ring-necked duck	X	X	X	-	X	-	X
Goldeneye	X	X	X	-	X	-	X
Hooded merganser	X	X	X	-	X	X	X
Great blue heron	X	X	X	-	X	X	X
California gull	X	X	X	-	X	-	X
Ring-billed gull	X	X	X	-	X	-	X
Forster's tern	X	X	X	-	X	-	X
Caspian tern	X	X	X	-	X	-	X
Kingfisher	X	X	X	-	X	X	-
Dipper	X	X	X	-	X	X	X
Birds of prey							
Red-tailed hawk	X	X	-	-	X	-	-
Bald eagle	X	X	X	-	X	X	-
Osprey	X	X	X	-	X	X	-
Peregrine falcon	X	-	-	-	X	-	-
Long-eared falcon	X	X	-	-	X	-	-
Long-eared owl	X	X	-	-	X	-	-
Spotted owl							
Upland game birds							
Grouse (spp.)	X	X	-	-	X	-	-
Quail (spp.)	X	X	-	-	X	-	-
Partridge (spp.)	X	X	-	-	X	-	-
Ring-necked pheasant	X	X	-	-	X	-	-
Mourning dove	X	X	-	-	X	-	-

TABLE 3.4 (Cont'd)

Species	Increased Access and Disturbance	Loss of Terrestrial Habitats	Loss of Stream Habitats and Creation of Open-Water Habitats	Interruption of Movement and Migration	Mortality at Transmission Lines	Reduction in Aquatic Prey	Degradation of Shoreline Habitats
Nongame land birds							
Yellow-bel1ied sapsucker	X	X		-	X	-	-
Downy woodpecker	X	X		-	X	-	-
Large carnivores							
Grizzly bear			-	-	-	X	X
Black bear			-	-	-	-	
Gray wolf			-	-	-	-	
Bobcal			-	-	-	-	-
Semiaquatic furbearers							
River otter	X	X	X	-	-	X	X
Mink	X	X	X	-	-	X	X
Muskrat	X	X	X	-	-		X
Beaver	X	X	X	-	-		X
Small game							
Mountain cottontail	X	X	-	-	-	-	X
Big game							
Elk	X	X		X			
Moose	X	X					
Mule deer	X	X		X			
White-tailed deer	X	X					

Beam, J.H. 1983. The effect of annual water level management on population trends of white crappie in Elk City Reservoir, Kansas. North American Journal of Fisheries Management 3:34-40.

Becker, C.D., D.H. Fickeisen, and J.C. Montgomery. 1981. Assessment of impacts from water level fluctuations on fish in the Hanford Reach, Columbia River. PNL-3813. Battelle Memorial Institute, Richland, Wash. 53 pages.

Bedrossian, K.L., R.D. Carleson, J.H. Noyes, and W.S. Potter. 1984. Status review of wildlife mitigation at Columbia Basin hydroelectric projects, Oregon facilities: final report. Oregon Department of Fish and Wildlife, Environmental Management Section, and U.S. Department of Energy, Bonneville Power Administration, Division of Fish and Wildlife, Portland, Ore.

Beiningen, K.T. and W.J. Ebel. 1970. Effects of John Day Dam on dissolved nitrogen concentrations and salmon in the Columbia River, 1968. Transactions of the American Fisheries Society 99:664-671.

Bell, M.C., A.C. DeLacy, G.J. Paulik, and R.A. Winnor. 1967. A compendium on the success of passage of small fish through turbines. Fisheries Engineering Research Program, U.S. Army Corps of Engineers, North Pacific Division, Portland, Ore. 267 pages.

Bentley, W.W. and E.M. Dawley. 1981. Effects of supersaturated dissolved atmospheric gases on northern squawfish, Ptychocheilus oregonesis. Northwest Science 55(1):50-61.

Bentley, W.W. and H.L. Raymond. 1976. Delayed migrations of yearling chinook salmon since completion of Lower Monumental and Little Goose Dams on the Snake River. Transactions of the American Fisheries Society 105:422-424.

Best, L.B., D.F. Stauffer, and A.R. Geier. 1979. Evaluating the effects of habitat alteration on birds and small mammals occupying riparian communities. Pages 117-124 in R.R. Johnson and J.F. McCormick, technical coordinators, Strategies for Protection and Management of Floodplain Wetlands and Other Riparian Ecosystems. General Technical Report WO-12. U.S. Department of Agriculture, Forest Service, Washington, D.C.

Brett, J.R. 1952. Temperature tolerance in young Pacific salmon, genus Oncorhynchus. Journal of the Fisheries Research Board of Canada 9:265-323.

Brooks, R.P. and W.E. Dodge. 1981. Identification of muskrat (Ondatra zibethicus) habitat in riverine environments. Pages 113-128; Worldwide Furbearers Conference Proceedings, Vol. 1, J.A. Chapman and D. Pursley, eds. Worldwide Furbearers Conference Inc., Frostburg, Md.

Brooks, R.P. and W.E. Dodge. 1986. Estimation of habitat quality and **summer** population density for muskrats on a watershed basis. Journal of Wildlife Management 50:269-273.

Bouck, G.R. 1980. Etiology of gas bubble disease. Transactions of the American Fisheries Society 109:703-707.

Canadian Department of the Environment. 1981. Environmental and safety concerns of hydroelectric power generation. Pages 96-106 in Nuclear Policy Review Background Papers. Canadian Department of the Environment, Ottawa, Ontario.

Canadian Department of Fisheries and Oceans. 1984. Toward a fish habitat decision on the Kemano completion project: a discussion paper. Canadian Department of Fisheries and Oceans, Vancouver, B.C. 75 pages.

Congleton, J.L., T.C. Bjornn, C.A. Robertson, J.S. Irving, and R.R. Ringe. 1984. Evaluating the effects of stress on the viability of chinook salmon smolts transported from the Snake River to the Columbia River estuary. Technical Report 84-4. Prepared by University of Idaho, Moscow, for U.S. Army Corps of Engineers. 67 pages.

Coon, J.C., R.R. Ringe, and T.C. Bjornn. 1977. Abundance, growth, distribution and movements of white sturgeon in the mid-Snake River. College of Forestry, Wildlife and Range Sciences, University of Idaho, Moscow. 63 pages.

Crouse, M.R., C.A. Callahan, K.W. Malueg, and S.E. Dominguez. 1981. Effects of fine sediments on growth of juvenile coho salmon in laboratory streams. Transactions of the American Fisheries Society 110:281-286.

Diamond, J. and H.J. Pribble. 1978. A review of factors affecting seaward migration and survival of juvenile salmon in the Columbia River and Pacific Ocean. Oregon Department of Fish and Wildlife, Research and Development Section, Corvallis, Ore. 103 pages.

Dodge, N.A. 1982. Columbia River Treaty: environmental impact. Journal of the Water Resources Planning and Management Division, Proceedings of the American Society of Civil Engineers 108(WR3):309-320.

Donohoe, R.W. 1966. Muskrat reproduction in areas of controlled and uncontrolled water-level units. Journal of Wildlife Management 30:320-326.

Dunn, C.A. 1975. 1974 Wynoochee Dam study: observation of 1974 juvenile out-migration, and evaluation of 1973 fish passage success from adult returns. Supplemental Progress Report. Washington State Department of Fisheries. 51 pages.

Dunn, C.A. 1978. Evaluation of downstream fish passage through multi-level outlet pipes at Wynoochee Dam. Progress Report 45. Washington Department of Fisheries. 96 pages.

Ebel, W.J. 1977. Panel 2: Fish passage problems and solutions to major passage problems. Pages 33-39; Proceedings Columbia River Salmon and Steelhead, March 5-6, 1976. Special Publication 10. American Fisheries Society.

Ebel, W.J. 1982. Effects of environmental degradation on freshwater stage of anadromous fish. Pages 147-180 in R.R. Mitsuoka, R.E. Pearson, L.J. Rutledge, and S. Waterman, eds., Fifty Years of Cooperation and Commitment: 1931-81. National Marine Fisheries Service, Northwest and Alaska Fisheries Center, Seattle, Wash.

Ebel, W.J. and C.H. Koski. 1968. Physical and chemical limnology of Brownlee Reservoir. Fishery Bulletin 67:295-335.

Ebel, W.J. and H.L. Raymond. 1976. Effect of atmospheric gas supersaturation on salmon and steelhead trout of the Snake and Columbia Rivers. Marine Fisheries Review Paper 1191.

Ebel, W.J., H.L. Raymond, G.E. Monan, W.E. Farr, and G.K. Tanonaka. 1975. Effect of atmospheric gas supersaturation caused by dams on salmon and steelhead trout of the Snake and Columbia Rivers. National Marine Fisheries Service, Northwest and Alaska Fisheries Center, Seattle. 110 pages.

Edge, W.D. and C.L. Marcum. 1985. Movements of elk in relation to logging disturbances. Journal of Wildlife Management 49:926-930.

Edwards, E.A., D.A. Krieger, A.M. Bactelles, and O.E. Maugham. 1982. Habitat suitability index models: black crappie. FWS/OBS-82/10/6. U.S. Fish and Wildlife Service, Habitat Evaluation Procedures Group, Fort Collins, Colo. 25 pages.

Edwards, E.A., D.A. Krieger, G. Gebhart, and O.E. Maugham. 1982. Habitat suitability index models: white crappie. FWS/OBS-82/10/7. U.S. Fish and Wildlife Service, Habitat Evaluation Procedures Group, Fort Collins, Colo. 22 pages.

Fickeisen, D.H. and M.J. Schneider. 1976. Gas bubble disease. CONF-741033. U.S. Energy Research and Development Administration.

Fitzner, R.E. et al. 1980. Bald eagles of the Hanford National Environmental Research Park. PNL-SA-8504. Prepared by Pacific Northwest Laboratory, Richland, Wash., for U.S. Department of Energy. 16 pages.

Fletcher, K. 1983. Biological impacts of small scale hydropower. Pages 51-57 in P. Dyer, ed., Small-Scale Hydropower: How Does It Fit the NW Energy Environmental Picture? University of Wisconsin, Institute for Environmental Studies, Seattle.

Foster, B.R. and E.Y. Rahs. 1983. Mountain goat response to hydroelectric exploration in northwestern British Columbia. Environmental Management 7(2):189-197.

Fowler, J.A. 1978. Effects of a reservoir upon fish. Pages 51-64 in W.L. Chadwick, ed., Environmental Effects of Large Dams. Report by the Commission on Environmental Effects of the U.S. Committee on Large Dams. American Society of Civil Engineers, New York.

Fraley, J., D. Read, and P. Graham. 1981. Flathead River fishery study. Prepared by Montana Department of Fish, Wildlife, and Parks, Helena, for U.S. Environmental Protection Agency.

Fraser, J.C. 1972. Regulated discharge and the stream environment. Pages 263-285 in R.T. Gglesby et al., eds., River Ecology and Man. Academic Press, New York.

Freddy, D. J., W.M. Bronaugh, and M.C. Fowler. 1986. Responses of mule deer to disturbance by persons afoot and snowmobiles. Wildlife Society Bulletin 14:63-68.

Garcia, J., L. Loehr, K. Richter, and G. Ahlborn. 1983. Energy-related use conflicts for the Columbia River estuary. FWSlOBS-82/60. U.S. Fish and Wildlife Service, Washington, D.C. 500 pages.

Geen, G.H. 1974. Effects of hydroelectric development in Western Canada on aquatic ecosystems. Canadian Journal of Fisheries and Aquatic Science 31:913-927.

Gibson, G., R. Michimoto, F. Young, and C. Junge, Jr. 1979. Passage problems of adult Columbia River chinook salmon and steelhead, 1973-78. Prepared by Oregon Department of Fish and Wildlife, Portland, for U.S. Army Corps of Engineers.

Graybill, J.P., R.L. Burgner, J.C. Gislason, P.E. Huffman, K.H. Wyman, R.G. Gibbons, K.W. Kurko, Q.J. Stober, T.W. Fagnan, A.P. Stayman, and D.M. Eggers. 1979. Assessment of the reservoir-related effects of the Skagit project on downstream fishery resources of the Skagit River, Washington. FRI-UW-7905. Prepared for Seattle City Light by Fisheries Research Institute, University of Washington, Seattle. 602 pages.

Gregory, S. and D. Mackey 1983. Impacts of water levels on breeding Canada geese and the methodology for mitigation and enhancement in Flathead drainage. Annual report, 1983. Bonneville Power Administration and Confederated Salish and Kootenai Tribes, Pablo, Mont. 73 pages.

Grubb, T.G. 1980. An evaluation of bald eagle nesting in western Washington. Pages 87-103; Proceedings of the Washington Bald Eagle Symposium, R.L. Knight et al., eds. Washington Department of Game, Olympia.

Guenther, H.R., F.P. Sharpe, and P. Strauss. 1979. Mule deer losses - Mohawk Canal, Arizona; a problem identified - a solution sought. Pages 642-644 in Mitigation Symposium, G.A. Swanson, technical coordinator. General Technical Report RM-65. U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo.

Hamilton, J.A.R., L.O. Rothfus, M.W. Erho, and J.D. Remington. 1970. Use of a hydroelectric reservoir for the rearing of coho salmon (Oncorhynchus kisutch). Research Bulletin 9. Washington Department of Fisheries. 65 pages.

Hannan, H.H. 1979. Chemical modifications in reservoir-regulated streams. Pages 75-94 in J.V. Ward and J.A. Stanford, eds., The Ecology of Regulated Streams. Plenum Press, New York.

Hansen, A.J., M.V. Stalmaster, and J.R. Newman. 1980. Habitat characteristics, function, and destruction of bald eagle communal roosts in western Washington. Pages 221-229 in Proceedings of the Washington Bald Eagle Symposium, R.L. Knight et al., eds. Washington Department of Game, Olympia.

Heinzenknecht, G.B. and J.R. Paterson. 1978. Effects of large dams and reservoirs on wildlife habitats. Pages 101-147 in W.L. Chadwick, ed., Environmental Effects of Large Dams. Report by the Commission on Environmental Effects of the U.S. Committee on Large Dams. American Society of Civil Engineers, New York.

Henny, C.J., J.A. Collins, and W.J. Deibert. 1978. Osprey distribution, abundance, and status in western North America. Vol II: The Oregon population. Murrelet 59:14-25.

Holden, P.B. 1979. Ecology of riverine fishes in regulated stream systems with emphasis on the Colorado River. Pages 57-74 in J.V. Ward and J.A. Stanford, eds., The Ecology of Regulated Streams. Plenum Press, New York.

Horak, G.C. and J.E. Olsen. 1981. Measures to protect and improve fish and wildlife resources at hydropower developments. Pages 484-491; Waterpower '81: An International Conference on Hydropower. U.S. Army Corps of Engineers, Washington, D.C.

Horner, N. and T.C. Bjornn. 1981a. Status of upper Columbia and Snake River coho salmon in relation to the Endangered Species Act. Prepared by Idaho Cooperative Fishery Research Unit, University of Idaho, Moscow, for U.S. Fish and Wildlife Service. 45 pages.

Horner, N. and T.C. Bjornn. 1981b. Status of upper Columbia and Snake River spring chinook salmon in relation to the Endangered Species Act. Prepared by Idaho Cooperative Fishery Research Unit, University of Idaho, Moscow, for U.S. Fish and Wildlife Service. 63 pages.

Horner, N. and T.C. Bjornn. 1981c. Status of upper Columbia and Snake River summer chinook salmon in relation to the Endangered Species Act. Prepared by Idaho Cooperative Fishery Research Unit, University of Idaho, Moscow, for U.S. Fish and Wildlife Service. 58 pages.

Hubbell, P.M. 1973. Program to identify and correct salmon and steelhead problems in the Trinity River Basin. A report to Trinity River Basin Fish and Wildlife Task Force, California Department of Fish and Game. 70 pages.

Ingram, P. and L. Korn. 1969. Evaluation of fish passage facilities at Cougar Dam on the South Fork McKenzie River in Oregon. Closing report for U.S. Army Corps of Engineers. Fish Commission of Oregon. 76 pages.

Johnston, J.B., N.G. Benson, and B.D. King III. 1981. Values of ecological characterization studies to assess the effects of fresh water inflow to estuaries. Pages 155-164 in Proceedings of the National Symposium on Freshwater Inflow to Estuaries. FWS/OBS-81/04. U.S. Fish and Wildlife Service, Washington, D.C.

Junge, C. 1971. Effects of peaking operations on passage of adult salmonids over Columbia River dams. Prepared by Fish Commission of Oregon, Portland, for U.S. Army Corps of Engineers, Walla Walla District, Wash.

Kadlec, J.A. 1962. Effects of a drawdown on a waterfowl impoundment. Ecology 43:267-281.

Kaiser, M.S. and E.K. Fritzell. 1984. Effects of river recreationists on green-backed heron behavior. Journal of Wildlife Management 48:561-567.

Kaster, J.L. and G.Z. Jacobi. 1978. Benthic macroinvertebrates of a fluctuating reservoir. Freshwater Biology 8:283-290.

Klingeman, P.C. 1981. Environmental considerations in small hydro development in Oregon. Megawatts from Small Hydro Conference Proceedings, L.S. Slotia, ed. Water Resource Institute, Oregon State University, Corvallis.

Knight, R.L. and S.K. Knight. 1984. Responses of wintering bald eagle to boating activities. Journal of Wildlife Management 48:999-1004.

Knopf, F.L. 1985. Significance of riparian vegetation to breeding birds across an altitudinal cline. Pages 105-111 in R.R. Johnson and J.F. McCormick, technical coordinators, Strategies for Protection and Management of Floodplain Wetlands and Other Riparian Ecosystems. General Technical Report WO-12. U.S. Department of Agriculture, Forest Service, Washington, D.C.

Kraft, M.E. 1968. The effects of controlled dewatering on a trout stream. Masters Thesis, Montana State University, Bozeman, 31 pages.

Kraft, M.E. 1972. Effects of controlled flow reductions on a trout stream. Journal of the Fisheries Research Board of Canada 29:1405-1411.

Kroger, R.L. 1973. Biological effects of fluctuating water levels in the Snake River, Grand Teton National Park, Wyoming. American Midland Naturalist 89(2):478-481.

Lara, J.M. 1973. A unique sediment depositional pattern. Pages 387-394 in W.C. Ackermann, G.F. White, and E.B. Worthington, eds., Man-Made Lakes: Their Problems and Environmental Effects. Geophysical Monograph 17. American Geophysical Union, Washington, D.C.

Lehmkuhl, D. M. 1972. Change in thermal regime as a cause of reduction of benthic fauna downstream of a reservoir. Journal of the Fisheries Research Board of Canada 29:1329-1332.

Lehmkuhl, D.M. 1979. Environmental disturbance and life histories: principles and examples. Journal of the Fisheries Research Board of Canada 36:329-334.

Leopold, L.B., M.G. Wolman, and J.P. Miller. 1964. Channel with time. Chapter 11 in Fluvial Processes in Geomorphology. W.H. Freeman and Co. 522 pages.

Levenson, H. and J.R. Koplin. 1984. Effects of human activity on productivity of nesting ospreys. Journal of Wildlife Management 48:1374-1376.

Lewke, R.E. and 1.0. Buss. 1977. Impacts of impoundment to vertebrate animals and their habitats in the Snake River Canyon, Washington, Northwest Science 51:219-270.

Loar, J.M., L.L. Dye, R.R. Turner, and S.G. Hildebrand. 1980. Analysis of environmental issues related to small-scale hydroelectric development. Vol. I: Dredging. ORNL/TM-7228. Oak Ridge National Laboratory, Oak Ridge, Tenn. 142 pages.

Long, C.W., F.J. Ossiander, T.E. Ruehle, and G.M. Matthews. 1975. Survival of coho salmon fingerlings passing through operating turbines with and without perforated bulkheads and of steelhead trout fingerlings passing through spillways with and without flow deflectors. Final report. Prepared by National Marine Fisheries Service, Northwest and Alaska Fisheries Center, for U.S. Army Corps of Engineers.

Mains, E.M. 1977. Corps of Engineers responsibilities and actions to maintain Columbia Basin anadromous fish runs. Pages 40-43 in Proceedings Columbia River Salmon and Steelhead, March 5-6, 1976. Special Publication 10. American Fisheries Society.

McDonnell, J.A. and F.F. Gilbert. 1981. The responses of muskrats (Ondatna zibethieus) to water level fluctuations at Luther Marsh, Ontario. Pages 1027-1040 in Worldwide Furbearers Conference Proceedings, Vol. II. J.A. Chapman and D. Pursley, eds. Worldwide Furbearers Conference Inc., Forstburg, Md.

McNeill, W.J. and W.H. Ahnell. 1964. Success of pink salmon spawning relative to size of spawning bed materials. Special Scientific Report 469, Fisheries. U.S. Fish and Wildlife Service. 15 pages.

Montana Department of Fish, Wildlife, and Parks. 1984a. Wildlife impact assessment and mitigation summary, Montana hydroelectric projects. Vol. I: Libby Dam. Final report. Prepared for U.S. Department of Energy, Bonneville Power Administration, Division of Fish and Wildlife. 91 pages.

Montana Department of Fish, Wildlife, and Parks. 1984b. Wildlife impact assessment and mitigation summary, Montana hydroelectric projects. Vol. III: Hungry Horse Dam. Final report. Prepared for U.S. Department of Energy, Bonneville Power Administration, Division of Fish and Wildlife. 66 pages.

Moore, R. and T. Mills. 1977. An environmental guide to western surface mining. Part 2: Impacts, mitigation, and monitoring. FWS/OBS-78/04. U.S. Fish and Wildlife Service, Washington, D.C.

Mullan, J. W. 1980. Fish predation on salmonid smolts in the Columbia River system in relation to the Endangered Species Act. U.S. Fish and Wildlife Service, Leavenworth, Wash. 24 pages.

Neel, J.K. 1966. Impacts of reservoirs. Pages 575-593 in D.G. Frey, ed., Limnology in North America. University of Wisconsin Press, Madison.

Nelson, W. et al. 1976. Assessment of effects of altered stream flow characteristics on fish and wildlife. Vol. 1: Pacific Northwest region case studies. FWS/OBS-76/31. U.S. Fish and Wildlife Service, Fort Collins, Colo. 399 pages.

Odum, E.P. 1979. Ecological importance of the riparian zone. Pages 2-4 in R.R. Johnson and J.F. ,McCormick, technical coordinators, Strategies for Protection and Management of Floodplain Wetlands and Other Riparian Ecosystems. General Technical Report WO-12. U.S. Department of Agriculture, Forest Service, Washington, D.C.

Olier, W.H. 1974. Wildlife problems associated with hydropower reservoirs. Bulletin 3. Washington Game Department, Environmental Management Division, Olympia. 10 pages.

Oregon Department of Energy. 1983. Small scale hydroelectric power: Oregon development guide. Oregon Department of Energy, Salem. 72 pages.

Parker, F.L. 1976. Constructing and managing power plants to avoid adverse ecological impacts. Transactions of the North American Wildlife and Natural Resources Conference 41:361-370.

Penfound, W.T. 1953. Plant communities of Oklahoma lakes. Ecology 34:561-583.

Peters, J.C. 1982. Effects of river stream flow alteration on fishery resources. North American Journal of Fishery Management 7(2):20-22.

Petts, G.E. 1979. Complex response of river channel morphology subsequent to reservoir construction. Progress in Physical Geography 3(3):329-362.

Petts, G.E. 1980. Long-term consequences of upstream impoundment. Environmental Conservation 7(4):325-331.

Petts, G.E. 1984. Impounded rivers: perspectives for ecological management. John Wiley and Sons, New York.

Rakstad, D. and J. Probst. 1985. Wildlife occurrence in water impoundments. Pages 80-94 in M.D. Knighton, compiler, Water Impoundments for Wildlife: A Habitat Management Workshop. General Technical Report NC-100. U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station, St. Paul, Minn.

Raymond, H.L. 1968. Migration rates of yearling chinook salmon in relation to flows and impoundments in the Columbia and Snake Rivers. Transactions of the American Fisheries Society 97(4):356-359.

Raymond, H.L. 1969. Effect of John Day Reservoir on the migration rate of juvenile chinook salmon in the Columbia River. Transactions of the American Fisheries Society 98(3):513-514.

Raymond, H.L. 1979. Effects of dams and impoundments on migrations of juvenile chinook salmon and steelhead from the Snake River, 1966 to 1975. Transactions of the American Fisheries Society 108(6):505-529.

Reiser, D.W. and R.G. White. 1981. Effects of flow fluctuations and redd dewatering on salmonid embryo development and fry quality. Prepared by University of Idaho, Moscow, for U.S. Department of Energy, Bonneville Power Administration.

Reiser, D.W. and R.G. White. 1983. Effects of complete redd dewatering on salmonid egg-hatching success and development of juveniles. Transactions of the American Fisheries Society 112:532-540.

Ricker, W.E. 1975. Computation and interpretation of biological statistics of fish populations. Bulletin 191. Canadian Department of the Environment, Fisheries and Marine Service, Ottawa, Ontario.

Roberts, H.B. and G.S. Lind. 1977. Status of the American osprey in Oregon. Pages 215-222 in Transactions of the North American Osprey Research Conference, February 10-12, 1972, J.C. Ogden, ed., U.S. Department of the Interior, National Park Service.

Rochester, H., Jr., T. Lloyd, and M. Farr. 1984. Physical impacts of small-scale hydroelectric facilities and their effects on fish and wildlife. FWS/OBS-84/19. U.S. Fish and Wildlife Service, Washington, D.C.

Samson, F.B. 1979. Lowland hardwood bird communities. Pages 49-66 in R.M. DeGraaf, technical coordinator, Management of North Central and Northeastern Forest for Nongame Birds. General Technical Report NC-51. U.S. Department of Agriculture, Forest Service, Washington, D.C.

Schoeneman, D.E. and C.O. Junge, Jr. 1954. Investigations of mortalities to downstream migrant salmon at two dams on the Elwha River. Research Bulletin 3. Washington Department of Fisheries. 49 pages.

Schoeneman, D.E., R.T. Pressey, and C.O. Junge, Jr. 1961. Mortalities of downstream migrant salmon at McNary Dam. Transactions of the American Fisheries Society 90(2):57-72.

Sigler, J.W., T.C. Bjornn, and F.H. Everest. 1984. Effects of chronic turbidity on density and growth of steelheads and coho salmon. Transactions of the American Fisheries Society 113:142-150.

Skagen, S. K. 1980. Behavioral responses of wintering bald eagles to human activity on the Skagit River, Washington. Pages 231-241 in Proceedings of the Washington Bald Eagle Symposium. R.L. Knight et al., eds. Washington Department of Game, Olympia.

Slough, B.G. and R.M. Sadleir. 1977. A land capability classification system for beaver (Castor canadensis Kuhl). Canadian Journal of Zoology 55:1324-1335.

Smoker, W.A. 1953. Streamflow and silver salmon production in western Washington. Fisheries Research Paper 1(1):5-12. Washington Department of Fisheries.

Stalmaster, M.V. 1980. Management strategies for wintering bald eagles in the Pacific Northwest. Proceedings of the Washington Bald Eagle Symposium, R.L. Knight et al., eds. Washington Department of Game, Olympia.

Stalmaster, M.V. and J.R. Newman. 1978. Behavior responses of wintering bald eagles to human activity. Journal of Wildlife Management 42:506-513.

Stanford, J.A. and J.V. Ward. 1979. Stream regulation in North America. Pages 215-236 in J.V. Ward and J.A. Stanford, eds., The Ecology of Regulated Streams. Plenum Press, New York.

Stober, Q.J., R.W. Tyler, J.A. Knutzen, D. Gaudet, C.E. Ptrosky, and R.E. Nakatani. 1977. Operational effects of irrigation and pumped/storage on the ecology of Banks Lake, Washington. Final Report, June 1973 to September 1977. FRI-UW-7907. Prepared by the Fisheries Research Institute, University of Washington, for the U.S. Bureau of Reclamation.

Stober, Q.J., S.C. Crumley, D.E. Fast, E.S. Killebrew, R.M. Woodin, G. Engman, and G. Tutmark. 1982. Effects of hydroelectric discharge fluctuation on salmon and steelhead in the Skagit River, Washington. FRI-UW-8218. Fisheries Research Institute, University of Washington, Seattle. 302 pages.

Stockley, C. 1975. Injury and disease in Columbia River fishes associated with dams. Supplemental progress report: Columbia River Investigations. Washington Department of Fisheries. 21 pages.

Stockley, C. 1981. Columbia River sturgeon. Progress Report 150. Washington Department of Fisheries. 28 pages.

Stuber, R.J. 1982. Habitat suitability index models: black bullhead. FWS/OBS-82/10.14 U.S. Fish and Wildlife Service, Habitat Evaluation Procedures Group, Fort Collins, Colo. 26 pages.

Stuber, R.J., G. Gebhart, and O.E. Maugham. 1982. Habitat suitability index models: largemouth bass. FWS/OBS-82/10/15. U.S. Fish and Wildlife Service, Habitat Evaluation Procedures Group, Fort Collins, Colo. 33 pages.

Taylor, K.V. 1978. Erosion downstream of dams. Pages 165-186 in Environmental Effects of Large Dams. American Society of Civil Engineers, New York.

Thompson, L.S. 1978. Transmission line wire strikes: mitigation through engineering design and habitat modification. Pages 27-52 in M.L. Avery, ed., Impacts of Transmission Lines on Birds in Flight. FWS/OBS-78/48. U.S. Fish and Wildlife Service, Washington, D.C.

Trefethen, J.B. 1972. Man's impact on the Columbia River. Pages 77-98 in R.T. Oglesby et al., eds., River Ecology and Man. Academic Press, New York.

Trefethen, J.B. 1973. Man-made lakes and wildlife values. Pages 750-754 in W.C. Ackermann et al., eds. Man-Made Lakes: Their Problems and Environmental Effects. Geophysical Monograph 17. American Geophysical Union, Washington, D.C.

Trotzky, H.M. and R.W. Gregory. 1974. The effects of water manipulation below a hydroelectric power dam on the bottom fauna of the upper Kennebec River, Maine. Transactions of the American Fisheries Society 103(2):318-324.

Turbak, S.C., D.R. Reichle, and C.R. Shriner 1980. Analysis of environmental issues related to small-scale hydroelectric development. Vol. IV: Fish mortality resulting from turbine passage. ORNL/TM-7521. Oak Ridge National Laboratory, Oak Ridge, Tenn. 116 pages.

U.S. Army Corps of Engineers. 1975. Special report: Lower Snake River fish and wildlife compensation plan. U.S. Army Corps of Engineers, Walla Walla, Wash. 95 pages.

U.S. Fish and Wildlife Service. 1980. Columbian white-tailed deer. FWS/OBS-80/01.27. National Fish and Wildlife Laboratory, Office of Endangered Species, and the National Coastal Ecosystem Team, Office of Biological Services, U.S. Fish and Wildlife Service, Washington, D.C. 6 pages.

VanDyke, F.G., R.H. Brocke, H.G. Shaw, B.B. Ackerman, T.P. Hemker, and F.G. Lindzey. 1986. Reactions of mountain lions to logging and human activity. Journal of Wildlife Management 50:95-102.

Ward, J.V. and J.A. Stanford. 1979a. Ecological factors controlling stream zoobenthos with emphasis on thermal modification of regulated streams. Pages 35-55 in J.V. Ward and J.A. Stanford, eds., The Ecology of Regulated Streams. Plenum Press, New York.

Ward, J.V. and J.A. Stanford. 1979b. Stream regulation in North America. Pages 215-236 in J.V. Ward and J.A. Stanford, eds., The Ecology of Regulated Streams. Plenum Press, New York.

Weitkamp, D.E. and M. Katz. 1980. A review of dissolved gas super-saturation literature. Transactions of the American Fisheries Society 109:659-702.

White, R.G., J.H. Milligan, A.E. Bingham, R.A. Ruediger, T.S. Vogel, and D.H. Bennett. 1981. Effects of reduced stream discharge on fish and aquatic macroinvertebrate populations. Idaho Water and Energy Resources Research Institute, University of Idaho, Moscow. 283 pages.

Williams, G.L. 1985. Classifying wetlands according to wildlife value: applications to water impoundments. Pages 110-119 in M.D. Knighton, compiler, Water Impoundments for Wildlife: A Habitat Management Workshop. General Technical Report NC-100. U.S. Department of Agriculture Forest Service, North Central Forest Experiment Station, St. Paul, Minn.

Wood, M. and A. Olsen, 1984b. Wildlife impact assessment and mitigation summary, Montana hydroelectric projects: Vol. IIA: Thompson Falls Dam. Final Report. Prepared by Montana Department of Fish, Wildlife and Parks, Helena, for U.S. Department of Energy, Bonneville Power Administration, Division of Fish and Wildlife. 49 pages.

Wood, M. and A. Olsen, 1984a. Wildlife impact assessment and mitigation summary, Montana hydroelectric projects: Vol. IIB: Cabinet Gorge and Noxon Dams. Final Report. Prepared by Montana Department of Fish, Wildlife and Parks, Helena, for U.S. Department of Energy, Bonneville Power Administration, Division of Fish and Wildlife. 71 pages.

Woods, G.P. and R.M. Bradley. 1979. Mitigation of impacts affecting white-tailed deer at the Seven Mile Project, British Columbia. Pages 639-641 in G.A. Swanson, ed., The Mitigation Symposium. General Technical Report RM-65. U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo.

Young, W.C. 1973. Plants for shoreline erosion control in southern areas of the United States. Pages 798-803 in W.C. Ackermann, G.F. White, and E.B. Worthington, eds., Man-Made Lakes: Their Problems and Environmental Effects. Geophysical Monograph 17. American Geophysical Union, Washington, D.C.

Zakel, J.C. and D.W. Reed. 1984. Downstream migration of fish at Leaburg Dam, McKenzie River, Oregon, 1980 to 1983. Information Report 84-13. Oregon Department of Fish and Wildlife.

4 METHODS FOR ASSESSING THE EFFECTS OF SINGLE-PROJECT HYDROELECTRIC DEVELOPMENT

4.1 INTRODUCTION

This section discusses the methods that are commonly used for assessing the hydroelectric development effects identified in Sec. 3. The methods described have been applied primarily to the effects of single hydroelectric projects. Section 6 discusses the extent to which these methods can be incorporated into methodologies for assessing the cumulative effects of multiple projects.

Methods for single-project assessment use various assessment procedures, here called techniques, that have attained the stature of "tools of the trade." These techniques are used either singly or in combination in each assessment method to evaluate the future effects of a proposed development. Assessment techniques are distinct from techniques for actually measuring environmental effects, as might occur during pre- and postproject monitoring.

Environmental assessment methods for single projects and cumulative assessment methodologies both are generally composed of a combination of techniques. Such combinations allow the strengths of some techniques to offset the weaknesses of others. For instance, the use of a matrix format to present data obtained from an evaluative procedure may clarify the presentation of an analysis and facilitate a semiquantitative summation of the results. Thus, the capabilities and characteristics of each environmental assessment will depend on which techniques are used. It is important to understand both assessment techniques and methods, because they are the raw materials from which cumulative assessment methodologies can be developed.

4.2 ASSESSMENT TECHNIQUES

Eight assessment techniques are generally used in impact assessments. These techniques are used to accomplish the following tasks: (1) identifying each impact and the species and habitats impacted, (2) quantifying the magnitude of the expected impact, (3) interpreting the importance of each impact, (4) comparing alternatives, and (5) communicating the results to decision makers. Not all assessment techniques are equally useful for all of these tasks. Since an understanding of the capabilities of these techniques is essential before a cumulative assessment methodology can be recommended or developed for a given problem, each technique is discussed in general fashion in Sec. 4.2. Section 4.3 then discusses the specific application of these techniques to assessments of hydroelectric development projects.

Other discussions of assessment techniques can be found in Warner and Preston (1974), Jain et al. (1977), Bissett (1980), Clark et al. (1980), Rosenberg et al. (1981), Norton and Walker (1982), Shopley and Fuggle (1984), and Wathern (1984).

4.2.1 Ad Hoc Techniques

Ad hoc techniques are developed according to the requirements of **a** single, specific environmental assessment, and are meant to apply to that case alone (Clark et al. 1980). Ad hoc techniques can have any structure that solves the assessment problem. They are developed at the time of the assessment on the basis of the experience and professional judgment of the person or persons performing the assessment.

Ad hoc techniques are particularly useful when no other techniques are available or appropriate. Ad hoc techniques are often used to identify project impacts, unless a checklist is available. Ad hoc techniques can result in a quantitative estimation of impact, but they are often descriptive and unstructured. When such techniques present a limited opportunity for quantifying impacts, they rely heavily on worst-case assumptions or on bounding conditions that define a range of values that include the expected impacts. Since interpretation of the importance of impacts is often qualitative and subjective, ad hoc techniques are useful for this function. However, because these techniques are developed specifically for a single assessment at the time of the assessment, they are often poorly documented and unfamiliar to other scientists, members of the public, and decision makers. Therefore, when used alone, they are of limited usefulness to communicate assessment data. Because of this limitation, ad hoc techniques are also not useful for comparing alternatives.

Ad hoc techniques are found in both single-project and cumulative impact assessments. The use of a multidisciplinary team of experts (i.e., a panel) is a common feature of ad hoc cumulative assessments. Recent ad hoc cumulative assessments have been performed by NUS Corporation (1976), Maryland Department of Natural Resources (1982), California Department of Water Resources (1984), and U.S. Bureau of Reclamation (1984a,b).

4.2.2 Evaluative Techniques

The objective of evaluative techniques is to assess several impacts on a single quantitative scale in order to compare them, facilitate consideration of alternatives, perform decision analyses, and evaluate overall or aggregate impacts. Evaluative techniques are used after the project impacts have been identified by some other technique. Generally, environmental measurements are converted to a common scale of environmental quality, such as a scale ranging from 0 (worst possible state) to 5 (optimum state). The rating for each variable is then weighted to represent the relative significance of that variable, and the ratings are combined to yield an overall impact value.

Among the advantages of this technique are that it enables (1) a comprehensive measure of total impact to be produced, even for complex situations, (2) impact findings to be summarized in terms of one or a few numbers, (3) alternatives to be easily compared on an equivalent scale, and (4) the results of subjective, complex decision-making processes to be communicated. However, the synthesis of environmental data into a single scale requires considerable subjectivity. While this type of technique appears highly quantitative because it uses and manipulates ratings and indexes, the initial data may be very general and subjective. This technique could be very useful for multiple-project assessments because it is flexible, simplifies complex situations, and uses a common impact scale. However, the degree of subjectivity required to apply evaluative techniques increases with the complexity of an analysis.

Impact assessment approaches that use evaluative techniques include the habitat suitability index (Daniel and Lamaire 1974, U.S. Fish and Wildlife Service 1980, Schamberger et al. 1982, O'Neil and Schamberger 1983), the habitat quality index (U.S. Army Corps of Engineers 1980), and the importance index (Bonnicksen 1983). Other work incorporating or expanding on evaluative techniques has been done by Van der Ploeg and Vlum (1978), Kiely-Brocato et al. (1980), and Sheppard et al. (1982). Recent cumulative assessments containing evaluative techniques include studies on the San Joaquin, Salmon, and Snohomish Rivers (FERC 1984, 1986a, and 1986b, respectively).

4.2.3 Panels

A panel consists of experts who make decisions by arriving at a group consensus. This technique is commonly used to identify project impacts. The ability to provide expert comment and consensus-based opinion on subjective matters makes panels a useful and common environmental assessment tool, particularly for designing ad hoc techniques, evaluating impact significance, and comparing alternatives.

Panels are often used in conjunction with other techniques since some aspects of assessment are inherently largely subjective tasks. Panels often use evaluative techniques to score or weight impacts as part of a decision-making process. Structured panel procedures such as the Delphi method (Pill 1971, Zuboy 1981) are frequently used to assist in developing a consensus. Panels are sometimes criticized for being overly subjective, overly encompassing, and sensitive to their composition. Because they are useful for addressing complex or controversial problems, they often result in lengthy deliberations that are poorly communicated to others. Panels are likely to be important in cumulative impact assessments because of their flexibility and ability to incorporate subjective evaluations.

Environment Canada (1979) and Bonnicksen (1983) provide examples of environmental assessments in which panels played a large role.

4.2.4 Checklists

Checklists are lists of specific potential environmental impacts or potentially affected resources and habitats. Checklists may be general lists of impacts, habitats, or resources; hierarchical lists with defined parameters and criteria; or multidimensional lists in the form of a matrix. Checklists are useful for identifying and standardizing the consideration of impacts. However, checklists are descriptive and of little use in quantifying impacts, interpreting them, or communicating information about the assessment and its results. Consequently, checklists are of limited use for comparing alternatives or evaluating multiple-project impacts. Checklists have been developed for hydroelectric development (Cada and Zadroga 1981, 1982) and water supply development (Hagan and Roberts 1973).

4.2. 5 Matrices

Matrices are two-dimensional tables constructed of columns and rows. In environmental assessments, matrices often display combinations of project activities and environmental properties, e.g., with project features as rows and habitats as columns. At the intersection of each column and row (called a *cell*) a descriptor is placed to describe that particular combination. Cell descriptors can be in the form of text, symbols, or numbers.

Evaluative techniques often rely on matrices for presentation of results. Two checklists can also be combined into a matrix to show the interaction of items on the lists, e.g., as demonstrated in Tables 3.3 and 3.4. Matrices, alone, are not useful for quantifying impacts, but they provide an excellent way of presenting the quantitative results of modeling, mapping, and ad hoc techniques. Matrices are also a convenient way of presenting comprehensive information on project impacts, and they provide a concise visual summary of significant impacts. For these reasons, and because matrices have a high degree of flexibility and compatibility with other techniques, they are especially useful for comparing alternatives. However, they are not well adapted to assessment of nonlinear interactions or threshold effects or to interpretation of the significance of impacts, even though they are useful for summarizing the patterns of impacts and identifying key activities and environmental parameters. Matrices are also unsuited to evaluation of the spatial or temporal aspects of environmental impacts.

Matrix techniques were first formally proposed for environmental assessment by Leopold et al. (1971), and use of these techniques has been frequent. Further examples and descriptions of matrix techniques are provided by Fishcher and Davies (1973), Schlesinger and Daetz (1973), Carlisle and Lystra (1979), Manning and Montcrief (1979), and Vertrees (1985).

4.2.6 Mapping

Mapping techniques use a series of map overlays, each coded for information on one project, environmental impact, or resource variable. When the overlays are superimposed, the combinations give insight into impact location, magnitude, and interaction. Map overiays can be produced either by stacking transparencies together or by generating composite maps by computer. Computer mapping using geographic data bases has been developed (e.g., Giles et al. 1979) to handle large numbers of variables. It should be possible to combine geographic data bases with models to quantify impacts, but this approach has not yet been widely developed.

Mapping is an attractive technique for representing resource distributions, identifying impact areas, aggregating variables, and comparing site characteristics. Computer mapping can summarize a large data set in a readily understandable and spatially oriented manner. However, although mapping is an excellent way to communicate certain types of information, it cannot easily be used to assess impact magnitude, interaction, or significance or to compare alternatives.

Uses of mapping in environmental assessments have been described by Bailey et al. (1978) and Berwick et al. (1984).

4.2.7 Networks

Networks, flow diagrams, and system diagrams all refer to a single basic technique for illustrating the relationship among actions, impacts, and environmental conditions involved in an impact assessment. Components are illustrated by boxes or symbols, and linkages (or processes) among them by arrows. Sorenson (197 1) applied networks as a type of illustrated format to identify impacts. Gilliland and Clark (1981) and Couillard (1984) describe the network technique and its application to impact assessment. Based on the ecosystem function concepts of Odum (1971), the network technique has been modified to allow quantitative evaluation of impacts by expressing linkages in energy units. The use of a common unit of measurement to quantify the magnitude and interactions of impacts distinguishes networks from all other assessment techniques.

Networks are an effective technique for organizing and displaying processes that result in environmental impacts. Interactions among variables and secondary impacts are easily illustrated with a network diagram. Quantitative networks provide the additional advantage of enabling interactions and impacts to be evaluated on a single scale (usually energy flow), and they are the basis for system models. However, network diagrams become complex and intractable as components are added and system boundaries are expanded. Simplifying networks by reducing the number of components or linkages can result in overlooking important impacts. Quantitative networks can only evaluate one general class of impacts (e.g., ecological or economic), since there is no generally accepted common measurement unit representing all areas of impact. Consequently, networks are not comprehensive and cannot be used to evaluate the relative significance of various impacts. Comparison of alternatives is also difficult because networks cannot be used to synthesize and simplify complex situations.

The application of networks to multiple projects and cumulative assessments may be limited by data requirements and diagram complexity. Furthermore, with multiple projects, networks provide little ability to evaluate impacts on a comprehensive basis or to compare different project configurations.

4.2.8 Models

Models are representations of systems that can sometimes be illustrated by network diagrams. The use of a model, called simulation, is intended to imitate the behavior of a system under a given set of conditions. Models are used in environmental assessments to trace the relationships among environmental components and assess their response to altered conditions. While models can be conceptual, physical, or numerical, this review focuses on numerical, computer-run models only.

The utility of a model for impact assessment varies considerably because of the variety of styles, assumptions, and formats that can be used. In general, modeling tends to perform well in describing a system, since a model is designed to copy the behavior of the system. As such, models are a direct method for evaluating variable interactions and secondary impacts. Simplified models can be used for quantitative prediction of impact magnitude, but descriptive models are sometimes too complex and difficult for this purpose. However, all models carefully define important environmental variables and documentation of models is often very good. Therefore, models are useful for communicating the form and results of the assessment process to others.

The role of models in impact assessment has received considerable examination both in single-project methodologies (e.g., Frankiel and Goodall 1978, Munn 1983) and in comprehensive approaches (Holling 1978). Examples of applications are found in Auerbach (1978), Carter et al. (1979), Hunter (1979), Boyce (1980), Kumar (1980), Gilliland et al. (1985), Finni and Stevens (1985), and Simons et al. (1984).

4.3 COMMON METHODS FOR ASSESSING SINGLE-PROJECT EFFECTS ON FISH AND WILDLIFE

Typically environmental assessment involves several activities: (1) describing the nature of the impact, (2) identifying the impacted species or environmental parameter, (3) estimating the magnitude and duration of the impact, and (4) assessing the importance and significance of the impact. Some of these activities are descriptive, some are objective and quantitative, and some are subjective and evaluative. For this reason environmental assessment methods for single-project assessment often use a combination of the techniques described above.

4.3.1 Methods for Assessing Effects on Fish

4.3.1.1 Sedimentation and Erosion

Hydroelectric development frequently disrupts the existing equilibrium between sedimentation and erosion processes that determine stream channel shape and composition. Also, sediments may remain suspended in reservoir and stream waters for extended periods of time, causing changes in water transparency, temperature, and other physicochemical parameters. Assessing the effects of such changes on fish survival and reproduction requires, first of all, characterization and prediction of equilibrium conditions. Of the assessment techniques described in Sec. 4.2, modeling has been used most often for this task. Other techniques, such as ad hoc and evaluative techniques, have then been or can be applied to estimate the implications of changes in these equilibrium conditions on fish and fisheries.

Sediment transport models have been developed to predict stream substrate composition and suspended sediment loads in stream water. The applicability of such models to hydroelectric development impacts depends on site-specific characteristics and specific modeling assumptions. Data on stream morphology characteristics, hydraulic conditions, discharge regimes, and sediment sources are needed to permit modeling of the sedimentation and erosion processes (Loar et al. 1980). Some of this information, such as sediment source and load information, can be obtained through regional evaluations based on soil, geological, and land use information (Cline et al. 1981). Given such information, several models exist (Tywoniuk 1972, Bennett 1974, Flemming 1975, Milhous 1985) that can be applied to predict new sedimentation and erosion equilibrium conditions. The model predictions regarding sedimentation and erosion characteristics can then be related to stream quality for fisheries, on the basis of qualitative matrix techniques (Rickert and Beach 1978), statistical techniques (Leathe and Enk 1985), or ad hoc techniques.

When stream sedimentation and erosion processes change, stream channel morphology also changes, although this process may not become apparent for many years. Changes in stream morphology are accompanied by changes in fish habitat availability and quality. Some basic equations (models) are available for predicting stream channel changes given data on existing conditions, future stream discharges, and sediment loads (Leopold et al. 1964, Simons 1976). Attempts to quantitatively predict the response of stream channels to new conditions have not been highly successful, although qualitative predictions can generally be made (Simons et al. 1981). Qualitative predictions of future stream channel conditions can be useful in approximating the consequences of hydroelectric development on the quality and quantity of downstream fish habitats.

Considerable research has been conducted on salmonid spawning success (measured primarily by fry emergence from spawning gravel) in relation to stream sediment characteristics. Consequently, simple statistical models are available for predicting spawning success given stream substrate conditions (McNeil 1964, Phillips et al. 1975, Shirazi and Seim 1979, Adams and Beschta 1980, Lotspeich and Everest 1981). These statistical models can be used with sediment transport models to predict future spawning success rates under different stream development schemes.

The effects of suspended sediments (turbidity) in stream and lake waters on fish growth and survival have been documented (Cordone and Kelly 1961, Sorenson et al. 1977, Auld and Schubel 1978) and quantified through laboratory experiments (Herbert and Merkens 1961, Swenson 1978, Sigler et al. 1984) and field survey research (Swenson 1978). The results from these studies and others could be used to develop ad hoc criteria for assessing the impact of suspended sediment concentrations on fish, after sediment transport models are used to predict changes in suspended sediments.

Changes in stream channel structure result in changes in the type and quantity of habitats available for fish. Numerous methods have been developed for estimating the quality and quantity of fish habitats in a given stream reach. They include complex habitat models (Bovee 1982), simple models (Hickman and Raleigh 1982), indexes (Binns 1978), and evaluative criteria (U.S. Forest Service 1978, de Leeuw 1982, Oswood and Barber 1982). Any of these techniques could be combined with the results of stream morphology analyses to evaluate the consequences of stream channel restructuring.

4.3.1.2 Disturbance of Hazardous Waste and Nutrient Sinks

Dredging and the disposal of dredged material during the construction of hydroelectric facilities can result in the release of soluble nutrient and toxic substances and the resuspension of particulate matter containing high concentrations of phosphorus, nitrogen, heavy metals, and toxic organic compounds (Loar et al. 1980). The substances can occur in the project area as a result of mining, industry, and agriculture in the immediate vicinity or at points upstream within the watershed.

It is difficult to predict the environmental impact caused by the disturbance of hazardous waste and nutrient sinks without detailed knowledge of the sediments of the area to be dredged and the nature of the contamination. Contaminants are likely to be highly variable in their distribution within the watershed because of several factors, including the initial placement of toxic materials, regional climatic patterns, local topography, and stream morphology. The potential for the presence of contaminants within an area can be deduced from recent and historical land use in the watershed.

Laboratory studies of sediments can be used to more accurately determine the types and concentrations of contaminants. Loar et al. (1980) suggest the use of the standard elutriate test, which allows an estimation of the short-term release of contaminants from the dredged materials. This procedure involves the extraction, identification, and measurement of the chemical substances that are (1) dissolved in the interstitial water of the sediment and (2) loosely bound or sorbed to the sediment. A report by the National Academy of Sciences (1975) presents guidelines for the establishment of **a** sampling, analysis, and monitoring program for environmental contaminants.

The environmental effects of toxic substances present in dredged material can vary greatly and depends on the type of contaminant, water chemistry, and target organisms. Water quality criteria are presented in a report by the U.S. Environmental Protection Agency (1976). Criteria for the avoidance of adverse effects on aquatic life and human water supplies are presented for a wide variety of the likely contaminants of dredged materials. Loar et al. (1980) also present information on the sensitivity of several fish species and invertebrates to toxic substances. These criteria can be used to estimate the level of impact on aquatic organisms within and downstream of the project area.

4.3.1.3 Interference with Fish Migration

Hydroelectric facilities affect migratory fish in several ways. On upstream migrations, hydroelectric facilities may act as a total or partial block to upstream areas. Upstream passage facilities are only partially effective and may induce stress on fish using them. On downstream migrations, fish typically experience high levels of stress or mortality due to turbine or dam passage, delays in migration, and predation. Stress can also lead to increased mortality.

The effectiveness of upstream passage facilities at hydroelectric developments varies considerably, depending on site conditions and the type of passage technology used. Predictions of effectiveness for future facilities are generally based on evaluations of past performance at similar passage facilities, e.g., the tracking studies of Barry and Kynard (1986). Methods for assessing the effectiveness of a proposed passage facility are primarily ad hoc methods developed for a specific site, although Reiser and Peacock (1985) have developed a methodology based on hydraulic modeling to define categories based on evaluative criteria.

When hydroelectric facilities block access for migratory fish to upstream reaches, this segment of stream habitat is lost. The value of lost upstream habitats can be estimated using one or more of the numerous methods designed to inventory or quantify stream habitats. These methods can involve habitat models (Bovee 1982, Hickman and Raleigh 1982) or structured evaluative surveys (Duff and Cooper 1978, U.S. Forest Service 1978, de Leeuw 1982, Armour et al. 1983, Platts et al. 1983). Generally, these techniques require various morphological and physicochemical stream measurements and produce quantitative or qualitative estimates of lost stream habitats for specific fish.

Downstream-migrating fish frequently pass through hydroelectric facilities by following the main downstream current into the turbine intakes. Studies have been conducted to estimate the survival rates of these fish. Methods for determining the percentages of turbine mortality at existing structures include experiments with model turbines (Cramer and Oligher 1964) and mark-release-recapture experiments (Schoeneman and Junge 1961, Olson and Kaczynski 1980, Taylor and Kynard 1985). These studies can be used with estimates of the number of fish that would pass through turbine facilities in an ad hoc assessment of the numbers of fish killed or severely stressed.

Downstream bypass structures have been used at many hydroelectric facilities to minimize turbine mortality. Such structures are very similar to those designed to mitigate entrainment at power plant cooling water intakes, a problem that has received considerable research attention (see Jensen 1974). Rainey (1985) reviews the results of several site-specific evaluations of downstream bypass facilities. Studies of bypass effectiveness tend to employ ad hoc methods developed for each particular site but, in general, they rely on empirical data on operational characteristics and mark-recapture results (e.g., Raymond 1979). The information produced by such studies can be used in conjunction with the design characteristics of proposed hydroelectric facilities to qualitatively estimate bypass facility success.

Delays in downstream migration for anadromous fish become critical if migration is prolonged beyond the period when the fish's physiology changes from freshwater to saltwater adaptation. Delays occur at bypass facilities and in low-velocity impoundments. Research has addressed the physiology of smoltification (Pyefinch 1966, Zaugg et al. 1972, Adams et al. 1975) through the use of biochemical and physiological data on migrating fish. These studies identify the period and conditions necessary for transformation and, when combined with migration time estimates (such as those in Bentley and Raymond 1976, Raymond 1979) in an ad hoc assessment, they allow evaluation of the impact of time delays during migration.

Downstream-migrating fish passing over or through hydroelectric facilities can experience high levels of predation in tailrace or spillway discharge areas (Mullan 1980, Holden 1979). Also, impoundments may enable the development of populations of piscivorous species that feed on small migrating species. Studies of the extent of predation losses of migrating fish at existing facilities have employed mark-recapture techniques (Raymond 1979) and piscivour abundance and feeding studies (Bentley and Dawley 1981, Bennett et al. 1983). The specific information from such studies may indicate the general level of losses by this cause. For new hydroelectric facilities, the results of past investigations could be used in ad hoc evaluations to qualitatively estimate the potential seriousness of this impact.

Fish frequently experience some level of physiological stress from passing over dams or through turbines or passage facilities. Techniques for evaluating the stress level of fish have been used in migratory salmonid studies (Specker and Schreck 1980, Barton and Peter 1982, Congleton et al. 1984). In these studies, plasma samples from control and experimental fish have been analyzed to produce an index of physiological stress. Increased stress in fish is typically associated with increased susceptibility to disease (Bentley and Raymond 1976). Wood (1968) provides information on the diseases of migratory salmonid fishes. To date, no method exists to associate stress with disease in an assessment of proposed hydroelectric development.

4.3.1.4 Altered **Stream Flow**

Hydroelectric development frequently imposes artificial flow regimes downstream of the powerhouse discharge and in bypassed reaches. Altered flow conditions can include dewatering (loss of all stream flow) or highly fluctuating stream flows, depending on the project configuration and operation mode. All changes in stream flow affect the composition of aquatic habitats for fish. Consequently, methods for assessing the impact of altered stream flows on fish are primarily habitat-oriented. They range from complex hydraulic and habitat models (Bovee 1982) to simple methods based on historical stream discharge data, such as that of Tennant (1976). Many methods that analyze stream habitats with respect to flow changes incorporate a mix of quantitative modeling, empirical data on habitat and fish relationships, and qualitative, evaluative ratings (Northern Great Plains Resource Program 1974, Thompson 1974, Silvey 1976, Nelson 1980). These methods require different initial data, but all produce estimates of the relative effect of changes in stream flow on fish.

The methods discussed above could be used to quantify the quality of habitats prior to dewatering, but this level of detail may not be needed since dewatering represents total habitat loss. Structured evaluative survey methods (e.g., Duff and Cooper 1978, U.S. Forest Service 1978, de Leeuw 1982, Armour et al. 1983, Platts et al. 1983) are less time-consuming and provide adequate information on the general quality of the lost habitat as well as some capability to quantify losses.

4.3.1.5 Disruption of Food Production and Transport

Fish populations downstream of hydroelectric facilities may be affected by changes in the amount and timing of food availability. Reservoirs can increase food supplies downstream by discharging water containing entrained plankton, larval fish, and aquatic insects. Reservoir releases can alter the timing of food availability in both beneficial and detrimental ways, depending on fish feeding habits. In addition, impoundments, dams, and generating facilities can block and reduce the downstream drift of aquatic insects produced in upstream reaches. However, specific data demonstrating these effects on food availability are largely lacking and methods for assessing these effects have not been developed (Petts 1984).

Field studies at operating hydroelectric sites, such as those by Brusven and MacPhee (1976) and Brusven and Trihey (1978), which describe the effects of fluctuating hydroelectric dam releases on downstream invertebrate drift and availability, are necessary to provide information on which a prediction of the general magnitude and likelihood of effects can be based. Giger (1973) has evaluated the relationships among stream flow, food availability, and salmonid feeding behavior with regard to assessing the impacts of flow modifications on downstream fisheries. Matter et al. (1983) has conducted field sampling and analyses to determine the availability and timing of food organisms in reservoir discharges below a peaking hydroelectric facility. These studies provide examples of field study methods for documenting existing impacts and contribute information that could be used to make qualitative predictions of the potential for impacts from proposed developments.

4.3.1.6 Inundation of Stream Habitats

Reservoir construction associated with hydroelectric development frequently results in the inundation of stream habitats by impoundment. This impact represents a loss of stream habitat, the value of which must be assessed. The fishery value of lost habitat can be estimated using one of several methods designed to inventory or quantify stream habitat potential for fish. These techniques include habitat quality models (Bovee 1982, Hickman and Raleigh 1982) and evaluative surveys (Duff and Cooper 1978, U.S. Forest Service 1978, de Leeuw 1982, Armour et al. 1983, Platts et al. 1983). Generally, these methods require various morphological and physicochemical stream measurements and produce quantitative or qualitative estimates of the importance of lost stream habitats to specific species or life stages of fish. To estimate the effects of reduced stream habitat quality on the numbers of fish, ad hoc analyses must be developed.

4.3.1.7 Changes in Fishing Area, Opportunity, and Catch

The development of hydroelectric facilities may affect the type and availability of fishery resources in the project area and associated waters. The economic, recreational, and cultural benefits of fisheries may change, and the equitability of the distribution of resources may become a social issue.

Hydroelectric development can create new fisheries in impoundments that differ from the former stream fisheries in species and catch rates. At the same time, stream habitats lost due to dewatering, inundation, and other physical effects may reduce or eliminate stream fishery resources. Access to upstream reaches by fish and fishermen may also be altered by hydroelectric development. The net effect of changes in available fishery resources can be estimated using a variety of methods that analyze the economic value of these changes. The nonmonetary value of the recreational and cultural benefits of fisheries are assessed by evaluative techniques that assign equivalent economic values to such benefits.

The potential fishery yield of a new reservoir can be estimated with modeling techniques (Jenkins and Morais 1971, Hanson and Leggett 1982). Considerable research has been directed at predictive reservoir fish production models (see papers associated with Oglesby 1982), and there is now enough experience and data to allow reasonably good estimates of anticipated fishery yields. Reservoir fish production models require predictions of water quality and reservoir morphology combined with fishery yield statistics on similar existing reservoirs. These models result in estimations of the magnitude of fish yield.

The loss or reduced potential of stream fisheries after hydroelectric development varies, depending on the type of impacts anticipated for the project. The methods for assessing these impacts have been discussed above.

Estimates of changes in fish yield are not equivalent to changes in fishing area, opportunity, and catch, which are parameters of human use and the social value of fisheries. The significance of changes in fish yields are most often assessed in economic terms. Several methods are capable of estimating the value of an existing fishery, e.g., the travel-cost method (Palm and Malvestuto 1983, Loomis et al. 1985), the willingness-to-pay method (ECO Northwest 1984, Leathe and Enk 1985), and others. These economic assessment methods place a value on existing fisheries and can be used to estimate the value of new fishing opportunities. They require information on lost and gained fishing areas, the use of these areas, and the amount of money people have paid or are willing to pay for fishing. Estimates of fishery loss and gain are then expressed in monetary units. Economic evaluations of Pacific Northwest salmonid fisheries and assessment methods are available and have been applied in several cases (Tuttle et al. 1975, Kunkel and Janik 1976, Oregon Department of Fish and Wildlife 1977).

4.3.1.8 Changes in Water Quality

Direct water quality impacts from hydroelectric development generally result from the creation of impoundments, particularly those large enough to cause thermal stratification of the reservoir water to develop. In these cases, reservoir discharge may differ from natural river water in many physical and chemical characteristics. Changes in water quality are primarily analyzed through the use of models. The effects of such changes in water quality on habitat quality and fish production are then interpreted by less quantitative techniques, often on an ad hoc basis.

The major water quality impacts identified for the Columbia River Basin can be categorized as changes in (1) water temperature, (2) concentrations of dissolved gases (nitrogen and oxygen), and (3) nutrient transport. Methods for assessing each of these categories are separately reviewed below.

Water Temperature. Thermal impact assessment requires information on both predicted temperature changes and the thermal requirements and preferences of target species. Thermal baseline data are widely available for streams and rivers from the U.S. Geological Survey (through various reports, such as Moore 1964, 1968) or the U.S. Environmental Protection Agency (STORET system). For unmonitored streams, data on nearby streams similar in basin characteristics, flow cycle, and climate can generally be used to estimate baseline conditions. Ad hoc, qualitative assessments of thermal effects can be accomplished using species requirements, baseline conditions, and the pre- and postdevelopment experiences of other, comparable hydroelectric facilities. The above information can be used in conjunction with modeling techniques such as the Froude reservoir stratification index (Canter 1985) and stream temperature dynamics (Morse 1970, Novotony and Krenkel 1973, Theurer et al. 1984) to make quantitative predictions of future thermal conditions in downstream areas and reservoir discharges.

Thermal tolerances and preferences for fish have been compiled for a large number of species by Coutant (1972, 1977) and Brown et al. (1972). This type of data is often available in species and genera life history reviews such as the U.S. Fish and Wildlife Service's habitat suitability models. Data such as those presented by Brett (1952) on the thermal tolerances of Pacific salmon are useful in establishing threshold criteria for short-term temperature exposures. Research is needed to characterize the effect of modified seasonal thermal cycles on fish, although some work in this area has occurred (Milner 1985).

Dissolved Gas Concentrations. Nitrogen supersaturation occurs when water entrains large volumes of air and experiences high pressures, such as are associated with plunges into a reservoir tailrace. Nitrogen-supersaturated water is not in equilibrium with atmospheric conditions, and the excess gas is released into the atmosphere. Fish that are exposed to supersaturated nitrogen conditions develop supersaturated gas concentrations in their blood 'hat, when released, result in gas bubble disease. The process of gas supersaturation in water and its effects on fish are well documented (Fickeisen and Schneider 1976, Beiningen and Ebel 1970). Anticipated hydraulic conditions at a proposed hydroelectric facility can be analyzed by the physical and analytical methods presented by Richardson and Baca (1976), Schneider and D'Aoust (1976), and D'Aoust and Clark (1980). If supersaturated conditions are predicted, then data on the susceptibility of specific fish species and life stages to gas bubble disease under these conditions (Bouck 1980, Weitkamp and Katz 1980) can be used to estimate the effect of these conditions on fish. The experimental procedures of Dawley and Ebel (1975) and Knittel et al. (1980) can be used if additional information on susceptibility is needed for a particular target species.

If a reservoir stratifies and its hypolimnetic waters become anoxic, depressed dissolved oxygen levels can develop downstream of the reservoir. Physical and chemical processes leading to dissolved oxygen impacts downstream of reservoirs have been documented in a number of cases (Ebel and Koski 1968, Hannan 1979). Canter (1985) presents a simple model for assessing the potential of a new reservoir to stratify. This model can be used in conjunction with the eutrophication model of Walker (1982) to estimate the likelihood of anoxic hypolimnetic conditions that would result in oxygen-deficient reservoir discharges. Cada et al. (1982) present empirical modeling results useful in estimating noncompliance, in terms of the dissolved oxygen in discharges of existing facilities, with the U.S. Environmental Protection Agency's 5-mg/L dissolved oxygen criterion (U.S. Environmental Protection Agency, 1986). The extent of downstream dissolved oxygen deficiency can be evaluated using stream re-aeration rates determined on the basis of relationships presented in Churchill et al. (1962). In general, these models require basic data on hydrologic regimes, water chemistry, project design, and stream channel characteristics. The models produce quantitative results predicting the probability and extent of dissolved oxygen impacts below operating hydroelectric dams.

Nutrient Effects. Reservoirs tend to act as nutrient sinks, thereby altering nutrient transport to downstream areas. This effect may reduce downstream biological productivity and eventually change fish standing crops. Reservoir nutrient retention has not been as well documented and quantified as changes in temperature and dissolved oxygen levels. Consequently, methods available for analyzing this impact are few and tend to be complex. The ability to estimate reservoir nutrient concentrations depends primarily on reservoir inflow characteristics. Techniques for estimating reservoir nutrient loadings and their implications for reservoir limnology have been developed (Vollenweider 1968, Keeney 1978), but estimation of reservoir discharge nutrient loads requires more-detailed modeling of temporal and spatial distributions of nutrients within the reservoir. Limnological models incorporating nutrient dynamics (e.g., Soltero et al. 1973, 1974, Grimard and Jones 1982) can provide a basis for qualitative estimation of the potential for nutrient transport impacts in downstream areas.

4.3.1.9 Overharvest of Wild Stocks in Mixed-Stock Fisheries

Hydroelectric development may alter the stock composition of downstream fisheries by reducing individual run sizes or adding new runs by creating hatcheries to mitigate hydropower losses. Any disruption in the stock composition of existing downstream fisheries can result in reallocation of fishing effort among the different stocks composing the fishery. Multistock fishery management is a new area of research that lacks established methods primarily because of its complexity (McHugh 1980). Some multistock analysis methods have been developed (Hilborn 1976, Mar 1985) but require extensive data on each stock in the fishery. A study, equivalent to that needed to effectively manage a muitistock fishery, would be required in order to determine the impact of a single hydroelectric facility on harvest rates for various stocks in a multistock fishery. Consequently, this impact has not been specifically addressed with respect to individual hydroelectric facilities.

4.3.2 Methods for Assessing Effects on Wildlife

4.3.2.1 Increased Human Access and Disturbance

The construction of hydroelectric facilities frequently leads to increased human access to remote areas and increased disturbance to wildlife. Although disturbance to wildlife by human activities has been well documented (Sec. 3.3.1), there are no generally accepted assessment techniques for predicting the magnitude of this effect. Assessments use ad hoc techniques and frequently assume worst-case or bounding conditions. For example, many assessments assume that all animals are displaced in some area of disturbance around the construction area. Ad hoc techniques may also assume that the magnitude of the effect is related to the magnitude of the project, such as the (1) size of the workforce, (2) size of the construction area, (3) length of the construction period, (4) type and dimensions of access roads and transmission corridors, and (5) timing of the construction period with respect to seasonal use by, and the life cycles of, wildlife species. Ad hoc techniques may also include assumptions about the sensitivity of animals to disturbance. This information is primarily used as part of a qualitative evaluation of the response of wildlife based on the professional judgment and experience of *he person or persons conducting the assessment.

Construction noise alone (e.g., from blasting or heavy equipment operation) can trigger abandonment of the affected area by sensitive species. The types of equipment and techniques used in construction also affect the magnitude of wildlife disturbance due to noise. The noise levels generated by construction equipment can be estimated with models (e.g., Bolt Beranek and Newman Inc. 1984). The effect of noise on receptors, i.e., humans or animals, can then be assessed using studies that define their response to various noise levels. Response to noise in rural areas is usually described by qualitative categories regarding the state or behavior of the receptor. Receptor sensitivity has been studies only for humans, but it is often assumed that the effects of noise are the same on animals as on humans (National Research Council 1977).

In sum, noise generated by construction activities can be quantitatively modeled, and the response of wildlife to noise can be qualitatively described. However, assessing the effect of such noise on the distribution and abundance of wildlife would require the use of the same types of ad hoc techniques as described above for other types of disturbances. The professional judgment and experience of the person or persons conducting the assessment would be needed.

4.3.2.2 Reduction in Aquatic Prey

All phases of hydroelectric development (construction, impoundment, diversion, and operation) can interact to bring about a reduction in the abundance of aquatic prey (see Sec. 3.3.2). Methods for assessing changes in fish abundance due to hydroelectric development are discussed in Sec. 4.3.1. These estimates can be used to assess the effects of reductions of aquatic prey on wildlife with further site-specific information on the abundance, distribution, habits, and feeding ecology of the affected wildlife species.

Models or evaluation procedures are not available specifically to evaluate the influence of prey abundance on the abundance and distribution of the species. Habitat suitability models (which are checklists) and/or literature reviews have been assembled for all of these species, except hooded mergansers (Roberts et al. 1985). However, the models may not contain enough information on the relationship of predator and prey to quantitatively evaluate the effect of prey reductions on each species. If not, ad hoc techniques could be used with some very simple assumptions about predator/prey relations based on the professional judgment and experience of the person or persons doing the assessment.

4.3.2.3 Loss of Critical Terrestrial Wildlife Habitats

The building of impoundments and project-related facilities can result in the loss of important terrestrial wildlife habitats, including riparian habitats, islands, wetlands, old-growth forest, and local high-use areas such as rookeries or wintering areas. Impacts can occur to wildlife habitats both upstream and downstream of the project as well as away from the immediate area if new access roads or power corridors are established.

The data needed for assessing the quantity of habitats lost include (1) the amount and types of terrestrial habitat affected, (2) the relative value of the area to wildlife, (3) the current use of the area by wildlife (e.g., for feeding, breeding, or roosting), and (4) the population densities of species of concern within these habitats. These data would then be incorporated into an ad hoc assessment of the magnitude of habitat lost. The amount (area) and types of habitats in the project area can be determined from aerial photographs and topographic maps of the site. Small-scale (1:20,000) aerial photographs, obtainable from the U.S. Geological Service, are sometimes adequate for this purpose. Large-scale (1:2,000) color infrared aerial photographs may be required to accurately delimit habitat boundaries and can provide more-detailed information, e.g., on vegetation type or the percentage of ground cover (Cuplin 1985). (These large-scale photographs must generally be acquired via contract with the U.S. Bureau of Land Management.) Ground surveys could be used to verify photograph interpretations. Plant species that are characteristic of different habitats in the Columbia River Basin (listed in Franklin and Dyrness 1973) can be used to help delineate the habitat areas affected by projects in that area.

The value of terrestrial habitats to wildlife can be estimated using the habitat evaluation procedures (HEP) developed by the U.S. Fish and Wildlife Service (1980). According to these procedures, each habitat type is evaluated in the field by a team of biologists. Data collected within the project area are used to develop a habitat suitability index for each species of concern based on models of the relationships between habitat characteristics and species requirements. Habitat suitability indexes have been developed for many of the species listed in Sec. 2 (Roberts et al. 1985). The stream corridor inventory and evaluation system (Garcia 1985) is very similar to the HEP in procedure and application.

To estimate changes in wildlife populations due to habitat changes, population density estimates should be available for all species of concern in the project area and vicinity. Sometimes this information is available for the region from state agencies, especially if the species is of economic importance (e.g., game species). Data on population density can be used in conjunction with the area of affected habitat and change in habitat suitability to make an ad **hoc** estimate of the number of animals lost as a consequence of project development. If data are not available, a variety of methods, ranging from detailed density estimates to density indexes (summarized in Miller 1984), can be used to estimate population density. If population data are unavailable, a comparison of estimated habitat value before and after the project (e.g., through the HEP) may have to suffice for the assessment, unless the person doing the assessment feels confident that professional judgment and experience can be reasonably used to determine the upper or lower bounds of the effects of habitat loss on population numbers.

4.3.2.4 Loss of Stream Habitats and Creation of Open-Water Habitats

Hydroelectric development usually involves the loss of stream habitats and the creation of open-water habitats as stream waters are impounded behind a dam. Species that use stream habitats for feeding may be negatively affected by stream loss. Some species, however, may benefit from the creation of large open bodies of water because of an increase in food supply (e.g., warm-water fish, aquatic macrophytes).

The data needed for assessing the impact of stream habitat loss include the (1) amount of stream habitat affected, (2) relative value of the area to wildlife, (3) current use of the area by wildlife, and (4) population densities of the species of concern within the project area. To assess the impact of impoundments on wildlife, the following information is needed: (1) the surface area of the proposed impoundment, (2) the depth and shape of the impoundment, and (3) the amount of water level fluctuation expected in the impoundment.

The HEP (U.S. Fish and Wildlife Service 1980) described in Sec. 4.3.2.3 can be used to assess these types of impacts. The amount of bottom sediments exposed can be quantified using a model presented by Hildebrand (1980), which uses data that can be obtained from a topographic map. Information from this model can be used in conjunction with the HEP to determine the value of the project impoundment to wildlife.

4.3.2.5 Interruption of Movement and Migration

Hydroelectric facilities can sometimes form a barrier to movement for large mammals, especially if the project incorporates a large reservoir or aboveground diversion structures of great length. In order for a barrier to have a regionwide effect on wildlife, the barrier must block traditional wildlife migration routes or travel corridors. Barriers may also affect mammal populations on a local scale.

The magnitude of the migration blockage effect is related to the dimensions (length, width, and height) of the barrier, its proximity to travel corridors and migration routes, and the number of animals using the corridor. Many species may be able to cross small reservoirs and move around diversion structures, depending on the dimensions of the structures and the local topography. No information is available concerning the relationship between the size and placement of a structure and its capacity to act as a barrier to movement. Site-specific information and professional judgment and experience are required to estimate the impacts of barriers on wildlife in an ad hoc assessment.

4.3.2.6 Bird Mortality at Distribution and Transmission Lines

Electrical power produced by a hydroelectric generating facility is often transmitted from the project site via aboveground distribution lines. These lines can cause birds to die if they collide with or land on the lines and are electrocuted. Data needed to assess the effect of distribution and transmission lines on bird mortality include (1) the length of the line, (2) the types of habitat crossed by the line, (3) the bird species that use these habitats and their densities, and (4) pole or tower and line design, including the types, density, height, and configuration of wires. For these data, Thompson (1978) presents a checklist of criteria by which transmission line mortality can be qualitatively evaluated. This evaluation includes the use of professional judgment and experience.

4.3.2.7 Degradation of Shoreline Habitats

Fluctuating water levels can result in the deterioration of shoreline habitats that are important for certain wildlife species. The construction of hydroelectric dams produces changes in gradient, flow regime, and sediment load, resulting in changed patterns of bed erosion and sediment deposition that in turn can significantly alter shoreline habitats. Methods for assessing sedimentation and erosion impacts are presented in Sec. 4.3.1.1.

Data needed to assess the impact of shoreline degradation on wildlife include (1) the frequency and width of water-level fluctuations, (2) the length of shoreline affected above and below the dam, (3) predicted changes in stream geomorphology, (4) the distribution and abundance of aquatic macrophytes in the project area, (5) the nature of wildlife use of the shoreline in the project area (e.g., for nesting, feeding, denning), and (6) population densities of wildlife species using shoreline habitats.

The amount of bottom sediments exposed by water-level fluctuations (and therefore the area of shoreline and shallow water affected) can be estimated using the model of Hildebrand (1980). The resulting data can be used in conjunction with the HEP (U.S. Fish and Wildlife Service 1980) or a similar procedure to estimate impacts on wildlife. If population data are available, an estimate could be obtained of the number of animals lost as a consequence of project development. In the absence of population data, a comparison of estimated habitat value before and after the project would have to suffice.

4.4 REFERENCES

Adams, J.N. and R.L. Beschta. 1980. Gravel bed composition of Oregon coastal streams. Canadian Journal of Fisheries and Aquatic Sciences 37:1514-1521.

Adams, B.L., W.S. Zaugg, and L.R. IMcLain. 1975. Inhibition of saltwater survival and Na-K-ATPase elevation in steelhead trout (Salmo gairdneri) by moderate water temperatures. Transactions of the American Fisheries Society 104:766-769.

Armour, C.L., K.P. Burnham, and W.S. Platts. 1983. Field methods and statistical analyses for monitoring small salmonid streams. FWS/OBS-83/33. U.S. Fish and Wildlife Service.

Auerbach, S.I. 1978. Current perceptions and applicability of ecosystem analysis to impact assessment. Ohio Journal of Science 78:163-174.

Auld, A.H. and J.R. Schubel. 1978. Effects of suspended sediment on fish eggs and larvae. Estuarine Coastal Marine Science 6: 153-164.

Bailey, R.G., R.D. Pfister, and J.A. Henderson. 1978. Nature of land and resource classification: a review. Journal of Forestry 76:650-655.

Barry, T. and B. Kynard. 1986. Attraction of adult American shad to fish lifts at Holyoke Dam, Connecticut River. North American Journal of Fisheries Management 6:233-241.

Barton, B.A. and R.E. Peter. 1982. Plasma cortisol stress response in fingerling rainbow trout, Salmo gairdneri Richardson, to various transport conditions, anaesthesia, and cold shock. Journal of Fish Biology 20:39-51.

Beiningen, K.T. and W.J. Ebel. 1970. Effect of John Day Dam on dissolved nitrogen concentrations and salmon in the Columbia River, 1968. Transactions of the American Fisheries Society 99:664-671.

Bennett, D.H., P.M. Bratovich, W. Knox, D. Palmer, and H. Hansel. 1983. Status of the warmwater fishery and the potential of improving warmwater fish habitat in the lower Snake reservoirs: final report. Prepared by the Department of Fish and Wildlife Resources, University of Idaho, Moscow, for the U.S. Army Corps of Engineers, Walla Walla, Wash.

Bennett, J.P. 1974. Concept of mathematical modeling of sediment yield. Water Resources Research 10:485-492.

Bentley, W.W. and E.M. Dawley. 1981. Effects of supersaturated dissolved atmospheric gases on northern squawfish, Ptychocheilus oregonensis. Northwest Science 55:50-61.

Bentley, W.W. and H.L. Raymond. 1976. Delayed migrations of yearling chinook salmon since completion of Lower Monumental and Little Goose Dams on the Snake River. Transactions of the American Fisheries Society 105:422-424.

Berwick, S.H., R.A. Nisbet, and K.L. Reed. 1984. Spatial analysis for determining "region-of-influence" when predicting impacts on wildlife and other resources. Pages 91-97 in Issues and Technology in the Management of Impacted Western Wildlife: Proceedings of a National Symposium, R. Comer, ed. Thorne Ecological Institute, Boulder, Colo.

Binns, N.A. 1978. Evaluation of habitat quality in Wyoming streams. Pages 221-242 in A. Marmelstein, ed., Classification, Inventory, and Analysis of Fish and Wildlife Habitat. FWS/OBS-78/76. U.S. Fish and Wildlife Service.

Bisset, R. 1980. Methods for environmental impact analysis: recent trends and future prospects. Journal of Environmental Management 11:27-43.

Bolt Beranek and Newman Inc. 1984. Electric power plant environmental noise guide. Vols. 1 and 2. 2nd Ed. Prepared for the Edison Electric Institute.

Bonnicksen, T.M. 1983. Environmental impact studies: an interdisciplinary approach for assigning priorities. Environmental Management 7:109-117.

Bouck, G.R. 1980. Etiology of gas bubble disease. Transactions of the American Fisheries Society 109:703-707.

Bovee, K.D. 1982. A guide to stream habitat analysis using the instream flow incremental methodology. Instream Flow Information Paper 12. FWS/OBS-82/26. U.S. Fish and Wildlife Service.

Boyce, S.G. 1980. Management of forests for optimal benefits (DYNAST-OB). Research Paper SE-204. U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station, Asheville, N.C. 92 pages.

Brett, J.R. 1952. Temperature tolerances in young Pacific salmon, genus Oncorhynchus. Journal of the Fisheries Research Board of Canada 9:265-323.

Brown, R.P., A.H. Rice, D.R. Perry, D.R. Danielski, and C.R. Bernick. 1972. A national compendium of freshwater fisheries and water temperature data. U.S. Environmental Protection Agency, Duluth, Minn.

Brusven, MA. and C. MacPhee. 1976. The effect of river fluctuations resulting from hydroelectric peaking on selected aquatic invertebrates and fish. Technical Report A-035-IDA. Idaho Water Resources Research Institute.

Brusven, M.A. and E.F. Trihey. 1978. Interacting effects of minimum flow and fluctuating shorelines on benthic stream insects. Technical Report A-052-IDA. Idaho Water Resources Research Institute.

Cada, G.F., K.D. Kumar, J.A. Solomon, and S.G. Hildebrand. 1982. Analysis of environmental issues related to small-scale hydroelectric development. Vol. VI: Dissolved oxygen concentrations below operating dams. ORNL/TM-7887. Oak Ridge National Laboratory, Oak Ridge, Tenn.

Cada, G.F. and F. Zadroga. 1981. Environmental issues and site selection criteria for small hydropower projects in developing countries. ORNL/TM-7620. Oak Ridge National Laboratory, Oak Ridge, Tenn. 47 pages.

Cada, G.F. and F. Zadroga. 1982. Small-scale hydroelectric power for developing countries: methodology of site-selection based on environmental issues. Environmental Conservation 9:329-337.

California Department of Water Resources. 1984. Enlargement of the east branch of the Governor Edmund G. Brown California Aqueduct. Final environmental impact report.

Canter, L. W. 1985. Environmental impact of water resources projects. Lewis Publishers, Chelsea, Mich.

Carlisle, R.K. and D.W. Lystra. 1979. Environmental impact assessment methodology of small-scale hydroelectric projects. Pages 492-497 in Waterpower '79: First International Conference on Small-Scale Hydropower. U.S. Army Corps of Engineers, Washington, D.C.

Carter, H.H., J.R. Schubel, R.E. Wilson, and P.M.J. Woodhead. 1979. Thermally induced biological effects caused by once-through cooling systems: a rationale for evaluation. Environmental Management 3:353-368.

Churchill, M-A., H.L. Elmore, and R.A. Buckingham. 1962. The prediction of stream reaeration rates. American Society of Civil Engineers, Journal of the sanitary engineering Division 89: l-46.

Clark, B.D., R. Bisset, and P. Wathern. 1980. Environmental impact assessment. Bowker, New York. 516 pages.

Cline, R., G. Cole, W. Megahan, R. Patten, and J. Potyondy. 1981. Guide for predicting sediment yields from forested watersheds. U.S. Forest Service, Northern and Intermountain regions, Missoula, Mont.

Congleton, J.L., T.C. Bjornn, C.A. Robertson, J.S. Irving, and R.R. Ringe. 1984. Evaluating the effects of stress on the viability of chinook salmon smolts transported from the Snake River to the Columbia River estuary: final report. Technical Report 84-4. Prepared by Idaho Cooperative Fishery Research Unit for the U.S. Army Corps of Engineers.

Cordone, A.J. and D.W. Kelley. 1961. The influence of inorganic sediment on the aquatic life of streams. California Fish and Game 47:189-288.

Couillard, D. 1984. New methodology of impact evaluation: coherence graphs. Journal of Environmental Management 18:253-265.

Coutant, C.C. 1972. Time-temperature relationships for thermal resistances of aquatic organisms, principally fish. ORNL-EIS/72-27. Oak Ridge National Laboratory, Oak Ridge, Tenn.

Coutant, C.C. 1977. Compilation of temperature preference data. Journal of the Fisheries Research Board of Canada 34:739-745.

Cramer, F.K. and R.C. Oligher. 1964. Passing fish through hydraulic turbines. Transactions of the American Fisheries Society 93:243-250.

Cuplin, P. 1985. Riparian area inventory and monitoring using large scale color infrared photography. Pages 69-71 in R.R. Johnson, et al., technical coordinators, Riparian Ecosystems and Their Management: Reconciling Conflicting Uses. General Technical Report RM-120. U.S. Forest Service, Rocky Mountain Forest and Range Experiment Station, Ft. Collins, Colo.

Daniel, C. and R. Lamaire. 1974. Evaluating effects of water resource developments on wildlife habitat. Wildlife Society Bulletin 2:114-118.

D'Aoust, B.G. and M.J.R. Clark. 1980. Analysis of supersaturated air in natural waters and reservoirs. Transactions of the American Fisheries Society 109:708-724.

Dawley, E.M. and W.J. Ebel. 1975. Effects of various concentrations of dissolved atmospheric gas on juvenile chinook salmon and steelhead trout. Fishery Bulletin 73:426-429.

de Leeuw, A.D. 1982. A British Columbia stream habitat and fish population inventory system. Pages 32-40 in N. Armantrout, ed., Acquisition and Utilization of Aquatic Habitat Inventory Information. Western Division of the American Fisheries Society, Bethesda, Md.

Duff, D.A. and J.L. Cooper. 1978. Techniques for conducting stream habitat surveys on national resource lands. Technical Note 283. U.S. Bureau of Land Management.

Ebel, W.J. and C.H. Koski. 1968. Physical and chemical limnology of Brownlee Reservoir. Fishery Bulletin 67:295-335.

EC0 Northwest. 1984. Economic evaluation of potential losses of fish populations in the Swan River. EC0 Northwest Inc., Eugene, Ore.

Environment Canada. 1979. Revised guide to the federal EARP. Environmental Assessment Panel, Ottawa. 12 pages.

Federal Energy Regulatory Commission. 1984. Draft environmental impact analysis of small-scale hydroelectric development in selected watersheds in the Upper San Joaquin River Basin, California. FERC/DEIA-0001. Office of Hydropower Licensing, Washington, D.C.

Federal Energy Regulatory Commission. 1986a. Salmon River Basin sixteen hydroelectric projects Idaho. FERC/DEIS-0044. Office of Hydropower Licensing, Washington, D.C.

Federal Energy Regulatory Commission. 1986b. Snohomish River Basin cluster impact assessment procedure, Washington. FERC/DElS-0042. Office of Hydropower Licensing, Washington, D.C.

Fickeisen, D.H., and M.J. Schneider. 1976. Gas bubble disease. CONF-741033. U.S. Energy Research and Development Administration.

Finni, G.R. and R. Stevens. 1985. Hydropower stacking. U.S. Environmental Protection Agency, Philadelphia. 180 pages.

Fishcher, D.W. and G.S. Davies. 1973. An approach to assessing environmental impacts. Journal of Environmental Management 1:207-227.

Flemming, G. 1975. Sediment erosion-transport-deposition simulator: state of the art. Pages 274-285 in Present and Prospective Technology for Predicting Sediment Yields and Sources. ARS-S-40. U.S. Department of Agriculture.

Frankiel, F.N. and D.W. Goddall, eds. 1978. Simulation modelling of environmental problems. Scope 9. John Wiley and Sons, New York. 112 pages.

Franklin, J.F. and C.T. Dyrness. 1973. Natural vegetation of Oregon and Washington. General Technical report PNW-8. U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station, Portland, Ore.

Garcia, J.C. 1985. A method for assessing the value of stream corridors to fish and wildlife resources. Pages 335-338 in R.R. Johnson, et al., technical coordinators, Riparian Ecosystems and Their Management: Reconciling Conflicting Uses. General Technical Report RM-120 U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station, Ft. Collins, Colo.

Giger, R.D. 1973. Streamflow requirements of salmonids: final report. AFS-62-1. Oregon Wildlife Commission, Research Division.

Giles, R.H., Jr., A.B. Jones, Ill, A.R. Tipton, and T.L. Sharik. 1979. Predicting impacts of proposed facilities in parks. Pages 1061-1066 in Proceedings of First Conference on Scientific Research in National Parks, R.M. Linn, ed. Vol. II. U.S. Department of the Interior, National Park Service, Washington, D.C.

Gilliland, M.W., L. Becker, R. Cady, J. Gabig, J. Gilley, R.A. Kern, A. Larson, Q.M. Nguyen, W. Powers, and R. Supalla. 1985. Simulation and decision-making: the Platte River Basin in Nebraska. Water Resources Bulletin 21:281-290.

Gilliland, M.W. and B.D. Clark. 1981. The Lake Tahoe Basin: A systems analysis of its characteristics and human carrying capacity. Environmental Management 5:397-407.

Grimard, Y. and H.G. Jones. 1982. Trophic upsurge in new reservoirs: a model for total phosphorous concentrations. Canadian Journal of Fisheries and Aquatic Sciences 39:1473-1483.

Hagan, R.M. and E.B. Roberts. 1973. Ecological impacts of water storage and diversion projects. Pages 196-215 in C.R. Goldman, ed., Environmental Quality and Water Development. W.H. Freeman and Co., San Francisco.

Hannan, H.H. 1979. Chemical modifications in reservoir-regulated streams. Pages 75-94 in J.V. Ward and J.A. Stanford, eds., The Ecology of Regulated Streams. Plenum Press, New York.

Hanson, J.M. and W.C. Leggett. 1982. Empirical prediction of fish biomass and yield. Canadian Journal of Fisheries and Aquatic Sciences 39:257-263.

Herbert, D.W.M. and J.C. Merkens. 1961. The effects of suspended mineral solids on the survival of trout. International Journal of Air and Water Pollution 5:46-53.

Hickman, T.J. and R.F. Raleigh. 1982. Habitat suitability index models: cutthroat trout. FWS/OBS-82/10.5. U.S. Fish and Wildlife Service.

Hilborn, R. 1976. Optimal exploitation of multiple stocks by a common fishery: a new methodology. Journal of the Fisheries Research Board of Canada 33:1-S.

Hildebrand, S.G., ed. 1980. Analysis of environmental issues related to small-scale hydroelectric development. Vol. III: Water level fluctuation. ORNL/TM-7453. Oak Ridge National Laboratory, Oak Ridge, Tenn.

Holden, P.B. 1979. Ecology of riverine fishes in regulated stream systems with emphasis on the Colorado River. Pages 57-74 in J.V. Ward and J.A. Stanford, eds., The Ecology of Regulated Streams. Plenum Press, New York.

Holling, C.S., ed. 1978. Adaptive environmental assessment and management. John Wiley and Sons, New York. 377 pages.

Jain, R.K., L.V. Urban, and G.S. Stacey 1977. Environmental impact analysis: a new dimension on decision making. Van Nostrand Reinhold Co., New York. 330 pages.

Jenkins, R.M. and D.I. Morais. 1971. Reservoir sport fishing and harvest in relation to environmental variables. Pages 371-384 in G.E. Hall, ed. Reservoir Fisheries and Limnology. Special Publication 8. American Fisheries Society, Bethesda, Md.

Jensen, L.D. 1974. Proceedings of the second entrainment and intake screening workshop. Report 15. John Hopkins University, Cooling Water Research Project, Baltimore, Md.

Keeney, D.R. 1978. A prediction of the quality of water in a proposed impoundment in southwestern Wisconsin. Environmental Geology 2:341-349.

Kiely-Brocato, K.A., G.J. Buhyoff, and W.A. Leuschner. 1980. An attitude matrix scaling system with relevance for resource management. Journal of Environmental Management 10:71-81.

Knittel, M.D., G.A. Chapman, and R.R. Garton. 1980. Effects of hydrostatic pressure on steelhead survival in air-saturated water. Transactions of the American Fisheries Society 109:755-759.

Kumar, S. 1980. A conceptual model for assessment of cumulative impacts of mining on hydrology. Pages 243-248 in Proceedings of the Symposium on Surface Mining Hydrology, Sedimentology and Reclamation. University of Kentucky.

Kunkel, C. and P. Janik. 1976. An economic evaluation of fisheries attributable to Siuslaw National Forest. Siuslaw National Forest, Corvallis, Ore.

Leathe, S.A. and M.D. Enk. 1985. Cumulative effects of micro-hydro development on the fisheries of the Swan River drainage, Montana. Bonneville Power Administration, Portland, Ore.

Leopold, L.B., M.G. Wolman, and J.P. Miller. 1964. Fluvial processes in geomorphology. W.H. Freeman and Co., San Francisco.

Leopold, L.B., F.E. Clarke, B.B. Hanshaw, and J.R. Balsley. 1971. A procedure for evaluating environmental impact. Circular 645. U.S. Geological Survey. 13 pages.

Loar, J.M., L.L. Dye, R.R. Turner, and S.G. Hildebrand. 1980. Analysis of environmental issues related to small-scale hydroelectric development. Vol. I: Dredging. ORNL/TM-7228. Oak Ridge National Laboratory, Oak Ridge, Tenn.

Loomis, J., D. Donnelly, and C. Sorg. 1985. Quantifying the economic effects of hydropower development on recreational fisheries: a case study in Idaho. Pages 139-144 in F.W. Olson, R.G. White, and R.H. Hamre, eds., Proceedings of the Symposium on small Hydropower and Fisheries, May l-3, 1985. American fisheries Society, Bethesda, Md.

Lotspeich, F.B. and F.H. Everest. 1981. A new method for reporting and interpreting composition of spawning gravels. Research Note PNW-369. U.S. Forest Service.

Manning, R.E. and L.W. Montcrief. 1979. Land use analysis through matrix modeling: theory and application. Journal of Environmental Management 9:33-40.

Mar, R.M. 1985. Exploitation of marine communities. Springer-Verlag, New York.

Matter, W.J., P.L. Hudson, and G.E. Saul. 1983. Invertebrate drift and particulate organic material transport in the Savannah River below Lake Hartwell during a peak power generation cycle. Pages 357-380 in T.D. Fontaine III and S.M. Bartell, eds., Dynamics of Lotic Ecosystems. Ann Arbor Science, Ann Arbor, Mich.

Maryland Department of Natural Resources. 1982. Power plant cumulative environmental impact final report. Power Plant Siting Program, Annapolis, Md. 354 pages.

McHugh, J.L. 1980. Coastal fisheries. Pages 323-346 in R.T. Lackey and L.A. Nielsen, eds., Fisheries Management. John Wiley and Sons, New York.

McNeil, W.J. 1964. A method for measuring the mortality of pink salmon eggs and larvae. Fish Bulletin 63:575-588.

Milhous, R.T. 1985. Sediment transport, instream flows, and the small hydro project. Pages 395-402 in F.W. Olsen, R.G. White, and R.H. Hamre, eds., Proceedings of the Symposium on Small Hydropower and Fisheries, May l-3, 1985. American Fisheries Society, Bethseda, Md.

Miller, S.A. 1984. Estimation of animal production numbers for national assessments and appraisals. General Technical Report RM-105. U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station, Ft. Collins, Colo.

Milner, A. 1985. Influence of water temperature and streamflow on sockeye salmon emergence and migration in Black Bear Creek, southeastern Alaska. Pages 54-58 in F.W. Olsen, R.G. White, and R.H. Hamre, eds., Proceedings of the Symposium on Small Hydropower and Fisheries, May l-3, 1985. American Fisheries Society, Bethseda, Md.

Moore, A.M. 1964. Compilation of water-temperature data for Oregon streams. U.S. Geological Survey, Portland, Ore.

Moore, A.M. 1968. Water temperatures in the lower Columbia River. Circular 551. U.S. Geological Survey.

Morse, W.L.L. 1970. Stream temperature prediction model. Water Resources Research 6:290-302.

Mullan, J.W. 1980. Fish predation on salmonid smolts in the Columbia River system in relation to the Endangered Species Act. U.S. Fish and Wildlife Service, Leavenworth, Wash.

Munn, R.E. 1983. The theory and application of modelling in environmental impact assessment. Pages 281-292 in Environmental Impact Assessment. PADC Environmental Impact Assessment and Planning Unit, University of Aberdeen, U.K. Martinus Nijhoff Publishers, Boston.

National Academy of Sciences. 1975. Principles for evaluating chemicals in the environment. Washington, D.C.

National Research Council. 1977. Guidelines for preparing environmental impact statements on noise: report of working group 69 on evaluation of environmental impact of noise. National Academy of Sciences.

Nelson, F.A. 1980. Evaluation of four instream flow methods applied to four trout rivers in southwest Montana. Montana Department of Fish, Wildlife, and Parks, Bozeman.

Northern Great Plains Resource Program. 1974. Instream needs sub-group report. Work Group C: Water.

Norton, G.A. and B.H. Walker. 1982. Applied ecology: towards a positive approach. Vol. I: The context of applied ecology. Journal of Environmental Management 14:309-324.

Novotny, V. and P.A. Krenkel. 1973. Simplified mathematical model of temperature changes in rivers. Journal of the Water Pollution Control Federation 45:240-248.

NUS Corporation. 1976. Overview environmental study of cumulative effects of electric power development in the Delaware River basin, 1975-1989, executive summary. NUS 3085. Prepared by NUS Corporation, Rockville, Md., for the Delaware River Basin Commission. 29 pages.

Odum, H.T. 1971. Environment, power and society. Wiley Interscience, New York.

Oglesby, R.T. 1982. The MEI symposium: overview and observations. Transactions of the American Fisheries Society 111:171-175.

Olson, F.W. and V.W. Kaczynski. 1980. Survival of downstream migrant coho salmon and steelhead trout through bulb turbines. Report prepared by CH2M Hill for Public Utilities District 1, Chelan County, Wenatchee, Wash.

O'Neil, L.J. and M.L. Schamberger. 1983. Habitat models as a monitoring tool. Pages 424-427 in J.F. Bell and T. Atterbury, eds., Renewable Resource Inventories for Monitoring Changes and Trends. College of Forestry, Oregon State University, Corvallis.

Oregon Department of Fish and Wildlife. 1977. Manual for fisheries management. Oregon Department of Fish and Wildlife, Fishery Division, Portland.

Oswood, M.E. and W.E. Barber. 1982. Assessments of fish habitat in streams: goals, constraints, and a new technique. Fisheries 7:8-11.

Palm, R.C., Jr. and S.P. Malvestuto. 1983. Relationship between economic benefit and sport fishing effort on West Point Reservoir, Alabama-Georgia. Transactions of the American Fisheries Society 112:71-78.

Petts, G.E. 1984. Impounded rivers. John Wiley and Sons, New York.

Phillips, R.W., R.L. Lantz, E.W. Claire, and J.R. Moring. 1975. Some effects of gravel mixtures on emergence of coho salmon and steelhead trout fry. Transactions of the American fisheries Society 105:461-465.

Pill, J. 1971. The Delphi method: substance, context, a critique and annotated bibilography. Socio-Economic Planning Science 5:57-71.

Platts, W.S., W.F. Megahan, and G.W. Minshall. 1983. Methods for evaluating stream, riparian, and biotic conditions. General Technical Report INT-138. U.S. Forest Service.

Pyefinch, K.A. 1966. Hydro-electric schemes in Scotland: biological problems and effects on salmonid fisheries. Pages 139-148 in R.H. Lowe-McConnell, ed., Man-Made Lakes. Academic Press, New York.

Rainey, W.S. 1985. Considerations in the design of juvenile bypass systems. Pages 261-268 in Proceedings on Small Hydropower and Fisheries. F.W. Olson, R.G. White, and R.H. Hamre, eds. American fisheries Society, Bethesda, Md.

Raymond, H.L. 1979. Effects of dams and impoundments on migrations of juvenile chinook salmon and steelhead from the Snake River, 1966 to 1975. Transactions of the American Fisheries Society 108:505-529.

Reiser, D.W. and R.T. Peacock. 1985. A technique for assessing upstream passage problems at small-scale hydropower developments. Pages 423-432 in Proceedings of the Symposium on Small Hydropower and Fisheries, F.W. Olson, R.G. White, and R.H. Hamre, eds. American Fisheries Society, Bethesda, Md.

Richardson, G.C. and R. Baca. 1976. Physics of dissolved gases and engineering solutions. Pages 118-119 in D.H. Fickeisen and M.J. Schneider, eds., Gas Bubble Disease. CONF-741033. U.S. Energy Research and Development Administration.

Rickert, D.A. and G.L. Beach. 1978. Assessing impacts of land management activities on erosion-related nonpoint source problems. Journal of the Water Pollution Control Federation 50:2439-2445.

Roberts, T.H., L.J. O'Neil, and W.E. Jabour. 1985. Status and source of habitat models and literature reviews, December 1984. Miscellaneous Paper EL-85-l. U.S. Army Corps of Engineers.

Rosenberg, D.M., V.H. Resh, S.S. Balling, et al. 1981. Recent trends in environmental impact assessment. Canadian Journal of Fisheries and Aquatic Science 38:591-624.

Schamberger, M., A.H. Farmer, and J.W. Terrell. 1982. Habitat suitability index models: introduction. FWS/OBS-82/10. U.S. Department of the Interior, U.S. Fish and Wildlife Service, Washington, D.C. 2 pages.

Schlesinger, B. and D. Daetz. 1973. A conceptual framework for applying environmental assessment matrix technololgies. Journal of Environmental Science 16: 11-16.

Schneider, M.J. and B.G. D'Aoust. 1976. Analytical methods. Pages 116-117 in D.H. Fickeisen and M.J. Schneider, eds., Gas Bubble Disease. CONF-741033. U.S. Energy Research and Development Administration.

Schoeneman, D.E. and C.O. Junge, Jr. 1961. Mortalities of downstream migrant salmon at McNary Dam. Transactions of the American Fisheries Society 90:58-72.

Sheppard, J.L., D.L. Wills, and J.L. Simonson. 1982. Project applications of the Forest Service Rocky Mountain Region wildlife and fish habitat relationships system. Transactions of the North American Wildlife and Natural Resources Conference 47:128-141.

Shirazi, M.A. and W.K. Seim. 1979. A Stream systems evaluation: an emphasis on spawning habitat for salmonids. EPA-600/3-790109. U.S. Environmental Protection Agency.

Shopley, J.B. and R.F. Fuggle. 1984. A comprehensive review of current environmental impact assessment methods and techniques. Journal of Environmental Management 18:25-47.

Sigler, J.W., T.C. Bjornn, and F.H. Everest. 1984. Effects of chronic turbidity on density and growth of steelheads and coho salmon. Transactions of the American Fisheries Society 113:142-150.

Silvey, L. 1976. R-2 cross program: a sag-tape method of channel cross section measurement for use with instream flow determination. U.S. Forest Service, Lakewood, Colo.

Simons, D.B. 1976. Management of river systems. Pages 255-289 in J.F. Orsborn and C.H. Allman, eds., Instream Flow Needs, Vol. 1. American Fisheries Society, Bethesda, Md.

Simons, D.B., R.M. Li, K.G. Eggert, R. Miskimins, J.N.H. Ho, W.T. Fullerton, V.M. Ponce and N. Duong. 1984. Simulation model for watershed management planning: project summary. EPA-600/S3-84-028. U.S. Environmental Protection Agency, Environmental Research Laboratory, Athens, Ga. 6 pages.

Simons, D.B., R.M. Li, and P. Lagasse. 1981. Proceedings: workshop on downstream river channel changes resulting from diversions or reservoir construction. FWS/OBS-81/48. U.S. Fish and Wildlife Service.

Soltero, R.A., J.C. Wright, and A.A. Horpestad. 1973. Effects of impoundment on water quality of the Bighorn River. Water Research 7:343-354.

Soltero, R.A., J.C. Wright, and A.A. Horpestad. 1974. The physical limnology of Bighorn Lake, Yellowtail Dam, Montana: internal density currents. Northwest Scientist 48:107-124.

Sorenson, J.C. 1971. A framework for identification and control of resource degradation and conflict in multiple use of the coastal zone. M.S. thesis (unpublished manuscript). Department of Landscape Architecture, University of California, Berkeley.

Sorenson, D.L., M.M. McCarthy, E.J. Middlebrooks, and D.B. Porcella. 1977. Suspended and dissolved solids effects on freshwater biota: a review. EPA-600/3-77-042. U.S. Environmental Protection Agency, Corvallis, Ore.

Specker, J.L. and C.B. Shreck. 1980. Stress response to transportation and fitness for marine survival in coho salmon (Onchorhynchus kisutch) smolts. Canadian Journal of Fisheries and Aquatic Sciences 37:765-769.

Swenson, W.A. 1978. Influence of turbidity on fish abundance in western Lake Superior. EPA-600/3-78-067. U.S. Environmental Protection Agency.

Taylor, R.E. and B. Kynard. 1985. Mortality of juvenile American shad and blueback herring passed through a low-head Kaplan hydroelectric turbine. Transactions of the American Fisheries Society 3:430-435.

Tennant, D.L. 1976. Instream flow regimes for fish, wildlife, recreation, and related environmental resources. Pages 359-373 in J.F. Orsborn and C.H. Allman, eds., Instream Flow Needs, Vol. 2. American Fisheries Society, Bethesda, Md.

Theurer, F.D., K.A. Voos, and W.I. Miller. 1984. Instream flow temperature model. Instream Flow Information Paper 16. FWS/OBS-84/15. U.S. Fish and Wildlife Service.

Thompson, K.E. 1974. Salmonids. Pages 85-103 in K. Bayha, ed., Anatomy of a River: An Evaluation of Water Requirements for the Hells Canyon Reach of the Middle Snake River. Hells Canyon Controlled Flow Task Force, Pacific Northwest River Basins Commission, Vancouver, Wash.

Thompson, L.S. 1978. Transmission line wire strikes: mitigation through engineering design and habitat modification. Pages 27-52 in M.L. Avery, ed., Impacts of Transmission Lines on Birds in Flight. FWS/OBS-78/48. U.S. Fish and Wildlife Service, Washington, D.C.

Tuttle, M., J. Richards, and R. Wahle. 1975. Partial net economic values for salmon and steelhead for the Columbia River system. National Marine Fisheries Service.

Tywoniuk, N. 1972. Sediment discharge computation procedures. Journal of the Hydraulics Division, American Society of Civil Engineers 98:521-540.

U.S. Army Corps of Engineers. 1980. A habitat evaluation system for water resources planning. Lower Mississippi Valley Division, Vicksburg, Miss. 89 pages.

U.S. Bureau of Reclamation. 1984a. Lower Gunnison Basin Unit, feasibility report: final environmental statement. U.S. Bureau of Reclamation, Salt Lake City. 318 pages.

U.S. Bureau of Reclamation. 1984b. Regulatory Storage Division, Central Arizona Project, final environmental impact statement. Vol. 1. U.S. Bureau of Reclamation, Boulder City, Nev.

U.S. Environmental Protection Agency. 1976. Quality criteria for water. Washington, D.C.

U.S. Environmental Protection Agency. 1986. Quality criteria for water 1986. EPA-440/5-86-001. U.S. Environmental Protection Agency, Office of Water Regulations and Standards.

U.S. Fish and Wildlife Service. 1980. Habitat evaluation procedures. ESM 102. U.S. Fish and Wildlife Service, Division of Ecological Services. Washington, D.C.

U.S. Forest Service. 1978. Stream reach inventory and channel stability evaluation. U.S. Forest Service, Northern Region.

Van der Ploeg, S.W.F., and L. Vlum. 1978. Ecological evaluation, nature conservtion and land use planning with particular reference to methods used in the Netherlands. Biological Conservation 14:197-221.

Vertrees, R.L. 1985. A matrix and accompanying classifications for identifying water research problems and needs. Water Resources Bulletin 21:115-133.

Vollenweider, R.A. 1975. Input-output models with special reference to the phosphorus loading concept in limnology. Schweizerische Zeitschrift fur Hydrologie 37:53-84.

Walker, W.W., Jr. 1982. A sensitivity and error analysis framework for lake eutrophication. Water Resources Bulletin 18:53-60.

Warner, M.L. and E.H. Preston. 1974. A review of environmental impact assessment methodologies. EPA-600/5-74-002. U.S. Environmental Protection Agency, Washington, D.C. 27 pages.

Wathern, P. 1984. Ecological modelling in impact analysis. Pages 80-98 in R.D. Roberts and T.M. Roberts, eds., Planning and Ecology. Chapman and Hail, New York.

Weitkamp, D.E. and M. Katz. 1980. A review of dissolved gas supersaturation literature. Transactions of the American Fisheries Society 109:659-702.

Wood, J.W. 1968. Diseases of Pacific salmon: their prevention and treatment. Washington Department of Fisheries, Hatchery Division, Olympia.

Zaugg, W.S., B.L. Adams, and L.R. McLain. 1972. Steelhead migration: potential temperature effects as indicated by gill adenosine triphosphatase activities. Science 176:415-416.

Zuboy, J.R. 1981. A new tool for fishery managers: the Delphi technique. North American Journal of Fisheries Management 1:55-59.

5 THE RELATIONSHIP OF SINGLE-PROJECT EFFECTS TO CUMULATIVE EFFECTS

Most of the methods described in the previous section can provide assessments of environmental effects that are due to only a single human activity. In reality, fish and wildlife populations are affected by a number of human activities that occur in different areas and/or at different times. The sum total of these effects is generally termed ***cumulative effects.*** This section reviews the definition of this term, surveys different types of cumulative effects, and outlines the characteristics needed in a methodology to assess the cumulative effects of hydroelectric development in the Columbia River Basin.

5.1 CUMULATIVE EFFECTS DEFINITIONS

5.1.1 Literature Surveyed

The word ***cumulative*** and its roots imply a 'heaping up" or successive addition of something, such as an impact. Cumulative effects refer to the effects of multiple projects on a common resource, a concept expressed in the definition of Stout (1985): "cumulative impacts occur when two or more projects affect a common resource." The same concept is also expressed by Lumb (1982) in his definition of the cumulative impacts of surface mining on hydrology: "the cumulation of flows and dissolved or suspended matter from all mine-permit sites and land uses to common downstream channels." The Council on Environmental Quality (CEQ) defines cumulative impact as "the impact on the environment which results from the incremental impact of the action when added to other past, present, and reasonably foreseeable future actions regardless of what agency (Federal or non-Federal) or person undertakes such actions. Cumulative impacts can result from individually minor but collectively significant actions taking place over a period of time" (CEQ 1978). The CEQ indicates that this definition includes both direct and indirect effects, but synergistic and other types of cumulative effects are not specifically mentioned. The CEQ definition is embedded in the regulations under the National Environmental Policy Act (NEPA). The "action" referred to in the definition is any one for which an environmental impact statement or other NEPA document is required.

Several other authors have also proposed definitions of cumulative environmental effects. In their discussion of forest practices, Geppert et al. (1984) define cumulative effects as "a change in the environment caused by the interaction of natural ecosystem processes with the effects of two or more forest practices." One important element in this definition is the concept that two or more effects are cumulative only if they interact. If no such interaction occurs, the effects are not cumulative even if a common resource is affected and the effects occur in the same area or time period. Another important element of this definition is that the effects that interact must stem from two or more actions (in this case, forest practices). Interacting effects from a single occurrence of a forest practice are not cumulative, but are either direct or indirect individual effects.

Horak and Vlachos (1984) define cumulative effects as "the interaction of effects of all current and reasonably foreseeable actions over time and space." They state that synergism is an important distinguishing characteristic between cumulative effects on one hand and direct (i.e., primary) and indirect (i.e.,secondary) effects on the other. However, in Table 2 of their report, they imply that incremental (i.e., nonsynergistic) effects are not cumulative, but then later include incremental effects in another definition of cumulative effects: "the total, interactive impacts over time, i.e., the sum of incremental, synergistic, and future actions over time and space."

5.1.2 Definition Adopted in This Report

For this report, *cumulative* effect is defined as "an environmental change resulting from the accumulation and interaction of the effects of one action with the effects of one or more other actions occurring on a common resource." This definition includes the concepts of (1) multiple actions, (2) actions occurring over both space and time, (3) different types of impact interactions, and (4) effects on a common resource. In the context of this report, this definition means that cumulative effects on fish and wildlife include impacts to their habitats and other environmental requirements, in addition to direct impacts on the individuals of a population.

This definition of cumulative effects does not restrict the time period over which they can accumulate. Cumulative effects can be either simultaneous, occurring during the same period, or serial, occurring one after another in time. If the impacts are simultaneous, there is no opportunity for moderation of the cumulative effect by recovery or adaptation of the population. If the impacts are serial, however, some populations or habitats may partially recover from one impact before experiencing the next. Complete recovery of a resource between impacts would negate the cumulative effects.

5.2 TYPES OF CUMULATIVE EFFECTS

The definitions of cumulative effects presented above illustrate several ways in which effects can become cumulative. Terms such as accumulation and interacting hint at different mechanisms of impact accumulation, which suggests one basis for distinguishing among different types of cumulative effects. In this report, the term ***additive*** will be used for cumulative effects that equal the sum of several occurrences of one type of effect from multiple projects, e.g., incremental losses of one type of habitat. In such cases, as illustrated in Fig. 5.1, the responses of some fish and wildlife species to those

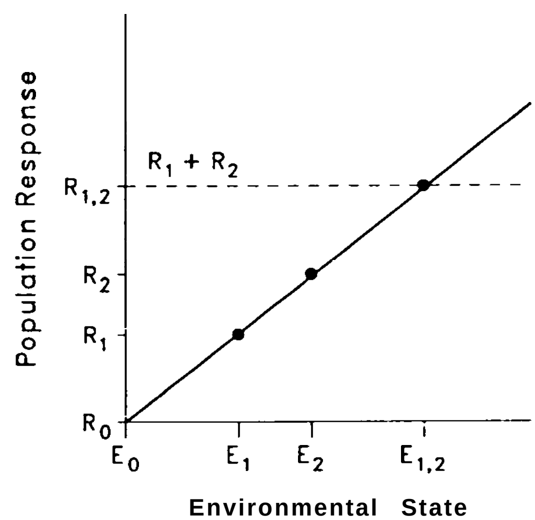


FIGURE 5.1 Additive Cumulative Effects (for projects 1 and 2)

multiple occurrences of environmental change are linear. Figure 5.1 illustrates response of a population to environmental state before project construction (E_0), after construction of a single project (E_1 or E_2), and after two projects are constructed ($E_{1,2}$). Since the curve is linear, the response of the population to environmental conditions after both projects are constructed ($R_{1,2}$) is the same as the sum of the response to each separate project (R_1 + R_2). Bain et al. (1986) distinguish two types of cumulative effects produced when multiple occurrences of an effect are not additive, i.e., when fish and wildlife responses to environmental changes are nonlinear. When the cumulative effect of several occurrences of one type of impact is greater than the sum of the impacts (see Fig. 5.2), it is referred to as a ***supra-additive*** cumulative effect, and when it is less than the sum of the impacts (see Fig. 5.3), it is an ***infra-additive*** cumulative effect. Many mechanisms may produce nonadditive cumulative effects. A sigmoid response curve contains regions where cumulative effects would be supra-additive, additive, and infra-additive (see Fig. 5.4).

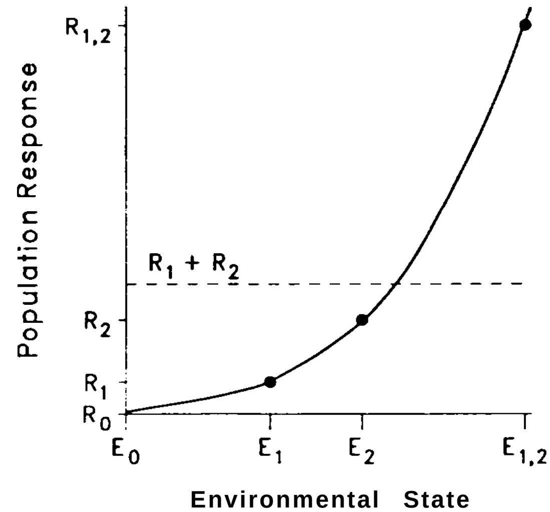


FIGURE 5.2 Supra-Additive Cumulative Effects (for projects 1 and 2)

Another type of cumulative effect, termed ***threshold*** effects, occurs when the biological response to increasing amounts or occurrences of the effect remains very low until some point after which the response becomes very high. Threshold effects are well described by the infra- and supra-additive definitions given above, and the cumulative effects presented in Figs. 5.1 and 5.3 would be difficult to distinguish from true threshold effects.

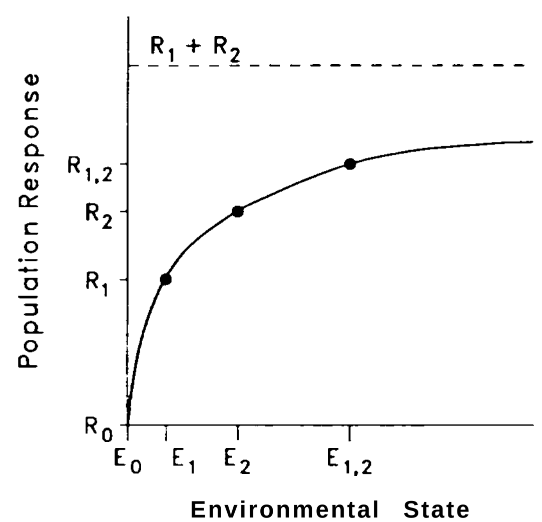


FIGURE 5.3 Infra-Additive Cumulative Effects (for projects 1 and 2)

The discussion up to this point has focused on interaction between occurrences of one type of effect. However, hydropower development has many different types of effects on the environment. Moreover, populations of fish and wildlife species are supported by an interacting system of environmental parameters. The final effect of changes in one environmental parameter is dependent on the state of or changes in others. These parameters can interact to either enhance or reduce an organism's response to environmental change. Thus, synergistic cumulative effects are produced when the total effect of several different kinds of impacts from multiple developments is greater than if the impacts had acted independently. For example, two different kinds of impacts that can occur from multiple occurrences of hydropower development and that behave synergistically are increased sedimentation and increased temperature in fish spawning gravels. The total effect of these impacts, reduced emergence of fry, could be greater than the sum of the reductions that would occur from each impact alone because both together might reduce the amount of oxygen available for egg development to levels below a biological threshold.

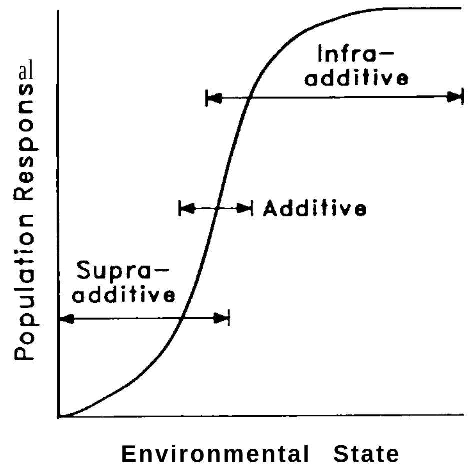


FIGURE 5.4 Example of a Sigmoid Response Curve with Regions of Supra-Additive, Additive, and Infra-Additive Cumulative Effects

Antagonistic cumulative effects are produced when the total effect of several different kinds of impacts is less than if the impacts had acted independently. An example of two environmental impacts that might be antagonistic and counteract each other would be increased sedimentation, which decreases the oxygen available to fish eggs incubating in gravels, and lower temperature, which increases the oxygen content of the water in fish spawning areas. If different effects act independently (neither synergistically or antagonistically), the overall combination of these effects would be additive.

Hence, the difference between supra-additive and synergistic cumulative effects (or, likewise, between infra-additive and antagonistic cumulative effects) is that, in the first case, the effects are of one type or affect a single environmental parameter (e.g., water temperature) whereas, in the second case, they are of different types or affect several environmental parameters (e.g., water temperature and sedimentation). In this report, the term accumulation will be used to indicate the calculation of the cumulative effect of all projects on one environmental parameter. The term aggregation will be used to indicate the calculation of the overall cumulative effect of all projects on a variety of environmental parameters. Accumulation involves one kind of information obtained through a single assessment method, while aggregation involves merging several kinds of information obtained through several different assessment procedures.

The National Research Council (NRC) Committee on the Applications of Ecological Theory to Environmental Problems identifies six different types of cumulative effects without proposing a formal definition (NRC 1986). These are (1) repeated actions in time, (2) repeated actions in space, (3) synergistic effects, (4) indirect effects, (5) "nibbling" or small incremental effects, and (6) other types of effects, including threshold and delayed effects. From the examples given by NRC, it is clear that five of the six types are related to multiple actions. The single exception is the category of indirect effects, for which a single-action example is given. All examples of cumulative effects identified by the NRC include effects on a common environmental process or entity.

In both the Horak and Vlachos and the NRC discussions of cumulative effects, the relationship between indirect and cumulative effects is not clear, and it is not stated whether all direct effects can be cumulative or whether cumulative effects include the indirect effects of multiple projects. The CEQ definition of cumulative effects clearly includes both the direct and indirect effects of multiple actions. Part of the confusion may come from use of the word cumulative in the assessment of single-project effects. In such assessments, the total effects of an action on a resource should be the sum of the direct and indirect effects that are induced by that action. When direct and indirect effects are combined in this manner, the total effect on the resource is sometimes erroneously described as cumulative.

5.3 METHODOLOGY REQUIREMENTS FOR ASSESSING CUMULATIVE EFFECTS OF HYDROPOWER DEVELOPMENT IN THE COLUMBIA RIVER BASIN

Examination of the cumulative effects of several hydropower activities on a common resource requires information on the distribution and timing of effects, the response of the resource system to impacts, the mechanism of cumulative interaction, and a statement of management goals. The last item, which reflects resource management approaches, is important because, although the resource of concern may be composed of distinct biological populations, each affected by only one project (and, therefore, not affected cumulatively by definition), these populations may be managed as a unit. In this case, resource management practices place the populations in interacting roles.

One population characteristic that increases the probability of cumulative effects is migration or wide-ranging movements, as occurs with anadromous fish, waterfowl, raptors, and some species of big game. Migration increases the chance of cumulative effects on a resource because individuals use a wide area where they may experience the effects of many actions and because the resource may be managed as a unit across geographical, biological, institutional, and political boundaries. All of the effects of hydroelectric development on fish and wildlife that were identified in Sec. 2 apply to migratory and wide-ranging species in the Columbia River Basin. Thus, any methodology recommended for application to the Columbia River Basin should be capable of including estimates of each of the effects identified in Sec. 2.

Also important to consider are the interactions between the effects of hydroelectric development and the effects of other activities. The hydropower effects identified in Sec. 2 are not unique to hydropower: they are also caused by other land and water use activities (see Fig. 5.5). For instance, sedimentation effects on fish result not only from the construction of hydropower facilities, but also from timber harvest, agricultural production, and recreation-related road construction. These interactions are very complex and often affect specific life stages or habitat requirements of a species.

Hydropower Effects	Nonhydropower Activities								
	Agricultural	Fishery	Mining	Recreational	Residential/ Industrial	Rood Construction	Timber Harvest	Waste Disposal	Water Supply
FISHERIES									
Sedimentation and Erosion	•		•	•	•	•	•	•	•
Disturbance of Hazardous Waste Sinks	•		•		•			•	
Interference with Fish Migration	•						•		•
Altered Stream Flow	•		•	•	•		•		•
Disruption of Food Production and Transport	•		•	•	•		•		•
Inundation of Stream Habitats	•								•
Fishing Area, Opportunity, and Catch	•	•	•	•	•	•	•	•	•
Changes in Water Quality	•		•	•	•	•	•	•	•
Overharvest of Wild Stocks in a Mixed-Stock Fishery	•	•							
WILDLIFE									
Increased Human Access and Disturbance	•	•	•	•	•	•	•		•
Reduction of Aquatic Prey	•	•	•	•	•	•	•	•	•
Loss of Critical Terrestrial Wildlife Habitats	•		•	•	•	•	•	•	•
Loss of Stream Habitats and Creation of Open-Water Habitats	•								•
Interruption of Movement and Migration	•		•		•	•	•		•
Bird Mortality at Transmission Lines	•				•				
Degradation of Shoreline Habitats	•		•	•	•	.	•	•	•

FIGURE 5.5 Effects of Hydropower on Fish and Wildlife that Also Occur from Other Activities in the Columbia River Basin

To help clarify whether a cumulative effect includes the effects of one or several types of actions, cumulative effects can be classified as follows:

- ***Heterotypic:*** cumulative effects that originate from multiple actions of more than one type, and

- ***Homotypic:*** cumulative effects that originate from multiple actions of the same type.

Some cumulative effects, such as upstream passage losses, are usually homotypic, i.e., caused by hydropower activities alone. Heterotypic and homotypic impacts can also be (1) additive, synergistic, or antagonistic and (2) simultaneous or serial.

The general requirements for a Columbia River Basin methodology include the following. First, the methodology should be able to evaluate the combined effects of more than one action. Second, it should have desirable characteristics for the study at hand. Third, it should support an integrated approach to hydropower planning, hydropower regulation, and fish and wildlife management. Fourth, it must be able to both accumulate and aggregate information.

The purpose of a cumulative effects assessment is to achieve a broader perspective for evaluating the significance of impacts to fish and wildlife from human activities than is possible by a single-project assessment. However, complete assessment of cumulative effects may not be possible because of the diversity of the impacted species, the diversity of types of hydropower effects, and the diversity of societal institutions calling for cumulative assessment. Because of expectations for continuing human activity and development in the basin, no single cumulative assessment study will be sufficient. The following section examines whether any existing assessment methodologies are applicable to a cumulative effects study for the Columbia River Basin.

5.4 REFERENCES

Bain, M.B., J.S. Irving, R.D. Olsen, E.A. Stull, and G.W. Witmer. 1986. Cumulative impact assessment: evaluating the environmental effects of multiple human development. ANL/EES-TM-309. Argonne National Laboratory, Argonne, Ill.

Council on Environmental Quality. 1978. Regulations for implementing the procedural provisions of the National Environmental Policy Act. 40 CFR, Parts 1500-1508. Federal Register 43:55978-56007.

Geppert, R.R., C.W. Lorenz, and A.G. Larson. 1984. Cumulative effects of forest practices on the environment: state of the knowledge. Ecosystems Inc., Olympia, Wash. 208 pp.

Horak, G.C. and E.C. Vlachos. 1984. Cumulative impacts and wildlife. Pages 7-13 in R. Comer, ed., Issues and Technology in the Management of Impacted Western Wildlife. Thorne Ecological Institute, Boulder, Colo.

Leathe, S.A., M.D. Enk, and P.J. Graham. 1985. An evaluation of the potential cumulative bioeconomic impacts of proposed small-scale hydrodevelopment on the fisheries of the Swan River Drainage, Montana. Pages 377-387 in Proceedings of Symposium on Small Hydropower and Fisheries, May l-3, 1985. F. W. Olson, R.G. White, and R.H. Hamre, eds., American Fisheries Society, Bethesda, Md.

Lumb, A.M. 1982. Procedures for assessment of cumulative impacts of surface mining on the hydrologic balance. Open-File Report 82-334. U.S. Geological Survey, Reston, Va. 50 pages.

National Research Council. 1986. Ecological knowledge and environmental problem-solving. National Academy Press, Washington, D.C.

Stout, D.J. 1985. A practical approach to cumulative impact assessment. Proceedings of Symposium on Small Hydropower and Fisheries, May l-3, 1985. F. W. Olson, R.G. White, and R.H. Hamre, eds., American Fisheries Society, Bethesda, Md.

6 EVALUATION OF EXISTING ASSESSMENT METHODOLOGIES

This section reviews 16 existing methodologies in terms of their usefulness for assessing the cumulative effects of hydroelectric development and operation on fish and wildlife in the Columbia River Basin. Because cumulative effects assessment is a new field, most of the methodologies reviewed were not developed specifically for this purpose. However, they were believed to have the potential for use in cumulative assessment, given some modification or expansion. The differences among the methodologies have necessitated different approaches to evaluation. Some of the more well-developed methodologies could be evaluated on the basis of their past performance under various circumstances. Others had to be evaluated solely on their potential for use in cumulative impact assessment. Consequently, the reviews below vary in the level of detail and specific topics addressed.

The following methodologies are reviewed:

- Adaptive environmental assessment and management (AEAM) methodology,
- Argonne multiple matrix (AMM) methodology,
- Cluster impact assessment procedure (CIAP),
- Habitat evaluation procedures (HEP),
- Instream flow incremental methodology (IFIM),
- INTASA methodology,
- Linear programming,
- Multiattribute utility analysis,
- Snohomish guidelines,
- Snohomish and Salmon River Basins methodology,
- Snohomish Valley environmental network,
- Swan River assessment methodology (SVEN),
- Target approach,
- Trinity Lakes assessment methodology,
- Water resources assessment methodology (WRAM), and
- Wetland functional assessment methodology.

The reviews are presented in alphabetical order. A comparison **of** methodologies is presented at the end of this section.

6.1 ADAPTIVE ENVIRONMENTAL ASSESSMENT AND MANAGEMENT METHODOLOGY

6.1.1 Description

The adaptive environmental assessment and management (AEAM) methodology was developed by Walters and Holling and was formally proposed as a methodology by Holling (1978). It consists of a procedure for developing models to explore diverse development or management strategies and outcomes (Holling 1982). The future conditions of a natural resource system are predicted through model simulation, rather than being projected from the system's existing conditions and from the experiences of other systems (Valiela 1984). The methodology has been used in at least 60 different applications around the world (Everitt 1983), including studies of forest pest management, fish stock management, tourist development, regional development, hydroelectric projects, and water resources (Wathern 1984). Consequently, application of the methodology is well documented. Training workshops on its use are conducted by its developers, and the U.S. Fish and Wildlife Service has had a trained AEAM team in Fort Collins, Colorado (Everitt 1983). Recently, the methodology has been used for evaluating hydroelectric power production and fishery dynamics in the Columbia River Basin (Webb et al. 1986).

The basic strategy of the AEAM methodology is to use an interdisciplinary team to perform a defined sequence of tasks that has feedback loops built into it so that improvements can be incorporated as they are discovered (see Fig. 6.1). The aim is to develop simulation models that are adequate for resource managers to use for investigating decision options, but that do not require a great deal of realistic detail. Although workshops and modeling are the main techniques used, checklists, matrices, mapping, and networks can be and are often used as well.

The first step of the AEAM methodology -- and one that is critical to its success -- is to assemble an appropriate core group to serve as the interdisciplinary team (Holling 1982). The team must include experts in appropriate disciplines or fields who are willing to work closely together. Usually, the research specialties represented include forest ecology, computer science or systems analysis, resource management, policy, economics, and other disciplines, as necessary.

The second step is to hold a workshop, at which the core group performs three main tasks:

- Scoping and bounding the task,
- Establishing a conceptual model, and
- Selecting subgroup members.

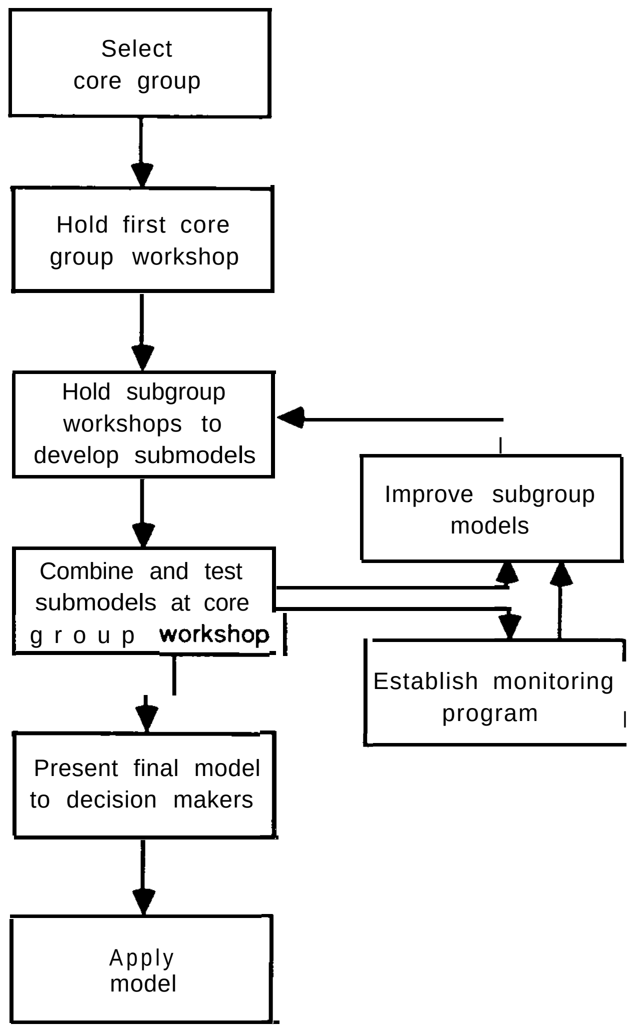


FIGURE 6.1 Flow Diagram of the AEAM Methodology

The scoping and bounding exercise involves (1) defining objectives and the relevant policy domain and (2) identifying the level of desired detail in terms of both a spatial and temporal scope. The conceptual model constructed defines the key variables of the resource system, i.e., those likely to be affected by the proposed project. To maintain efficiency in terms of time and cost, the AEAM methodology requires only a few physical, biological, and socioeconomic variables to be incorporated into the model. The resources examined can include both species and habitats.

After the conceptual model is formulated, the subgroups then conduct their own workshops to collect and synthesize existing, pertinent data. They develop submodels and identify important information gaps. The core group then meets again to integrate the submodels into a single simulation model. If, after testing, the model appears valid (based on various criteria or analyses), the group begins "gaming" with the model -- i.e., trying different initial conditions and investigating alternative development or management strategies. The purpose is often not to seek a single, optimal solution, although Walters and Hilborn (1978) provide an example where optimization is an objective, but rather to investigate a realm of possible alternatives or impact outcomes. The core group's results may suggest that portions of the model be improved or modified, leading to a feedback loop to one or more of the subgroups. The results may also suggest that a monitoring program be established for certain parameters. The results are communicated in an easily understood format and are made available to appropriate parties through oral presentations with visual aids.

In late 1985 and early 1986, the Northwest Power Planning Council sponsored a workshop series to introduce the AEAM methodology and use it in an application involving salmonid fisheries and power production in the Columbia River Basin. The product of this AEAM exercise was a computer simulation model with three submodels for freshwater salmonid fish production, downstream migration, and ocean survival and spawning escapement. As part of the model development, simulation modeling was conducted on selected subbasins of the Columbia River. The model produced is a tool for aiding the development of fishery management options and strategies. Consequently, the model is an AEAM product and not a test of the AEAM approach.

6.1.2 Evaluation

The demands for data, time, cost, and personnel are moderate with this methodology. An experienced core group could probably perform one complete assessment and several "rough cut" assessments per year (Holling 1978). Collecting and organizing existing data, largely through contacting appropriate agencies, might require one person-year of effort. An extensive data base is not required, and accumulation and generation of data are not encouraged. Data needs are tied closely to the assessment procedure from the start: one task of each workshop is to identify the specific types and quantity of data needed and, conversely, the types of data that are not needed. Stress is placed on the use of existing data rather than original data that would require substantial funds and personnel time to generate.

In general, the predictive capability of the models produced is low (Sondheim 1978, Bisset 1980, Ramp-Nielsen 1983, Valiela 1984). However, as noted by Holling (1978), the models can be improved by tests and reiterations. Also, the objective of the AEAM methodology is not to eliminate uncertainty in decision making, **but** to help decision makers realize risks and be able to choose alternatives with lower risks. Thus, in many applications, decision makers have not felt they gained a highly predictive tool, but rather, a much better understanding than before of the key parts of the resource system, the interactions among those parts, the management choices, and some likely responses of the system to those choices. For this reason, the methodology is perhaps best suited to large-scale or regional resource management assessments.

Despite potential problems with the models' predictive capability, the AEAM methodology has scientific credibility. Every step of the procedure is well documented, assumptions are succinctly stated, the best available information and expertise are used, and the model runs are repeatable. Simulation modeling is an accepted resource management tool. Its use in the AEAM methodology involves explicit (i.e., measurable) indicators or parameters and aims at documenting the magnitude of changes in those indicators over time. The concepts of uncertainty and thresholds are frequently incorporated. Also, the models are kept simple (i.e., to only a few component and process variables) to maintain their practical value to managers and decision-makers. Environmental effects are not aggregated into a single value or index. Modeling results for each resource are displayed graphically for each management option simulated. It is up to managers and decision makers to discuss and weigh the tradeoffs that emerge.

The AEAM methodology is designed to be flexible, so that public and agency input can be incorporated throughout the model development process. The methodology does not satisfy NEPA requirements, but that capability was never intended by its developers. Mitigative measures are not inherently considered, but these can easily be explored by running the model produced both with and without mitigative measures and contrasting the outcomes. More commonly, the output simply suggests areas where managers should concentrate mitigation efforts.

The applicability of the AEAM methodology to cumulative impact assessment is difficult to determine, since participant involvement in shaping the assessment process according to their objectives is one of the methodology's key features. The methodology appears to be best suited to basinwide planning or similar activities where long-term management, monitoring, and model refinement practices are anticipated. The success of the Northwest Power Planning Council in using the AEAM methodology will be determined by its contribution to the successful management of anadromous fisheries in the Columbia River Basin or subbasins. Until significant management decisions are implemented based on recent AEAM experiences, the significance of the methodology in managing power and fisheries in the Columbia River Basin will be unclear.

6.2 ARGONNE MULTIPLE MATRIX METHODOLOGY

6.2.1 Description

The Argonne multiple matrix (AMM) methodology was developed at Argonne National Laboratory to assess the effects of multiple hydroelectric developments for regulatory purposes (Bain et al. 1986). The methodology is intended for use after each proposed development has been evaluated individually and found to be environmentally acceptable or of limited environmental impact. Multiple criteria are applied to assess the impacts of all possible configurations (i.e., combinations) of the acceptable projects. The final outcome is a list of only those project configurations that meet all criteria used. The configurations assessed range from each proposed project alone to all of them together.

The methodology consists of three phases (see Fig. 6.2). In the first phase, impact analysis, impact ratings are assigned to each project from an evaluative scale of impact significance (e.g., 0 to 4). Matrix algebra is then used to combine these ratings to calculate the relative levels of impact for each configuration of projects. The matrix approach enables impacts on multiple target resources, with multiple components that may be affected, to be analyzed.

In addition to standardized ratings for component impacts, the matrix computations use weights to account for the relative importance of resource components and to develop coefficients of interaction between projects. Interaction coefficients are ratings used to modify the simple sum of multiproject impacts to account for nonadditive effects of multiple projects. The cumulative effects of multiple projects are basically calculated by a simple formula:

Total effect = sum of project effects + interaction effects

The latter term refers to interactions among the effects of separate projects. The product of the analysis phase is a set of total-impact ratings for each target resource for each configuration on a relative numerical scale.

In the second phase, evaluation, all possible project configurations are screened to identify one or a few preferred configurations. The screening process begins as a separate activity of each staff member and then continues as a interactive team effort. Screening criteria are maximum allowable total-impact values for each target resource. A customized computer program assists with repetitive screening of project configurations because of the typically large number of possible configurations. The goal is to obtain a list of configurations that satisfy all individual resource criteria.

The final phase, documentation, employs no special technique other than clear and concise documentation of the expected impacts for the final recommended configuration(s). Summary material may be presented in tabular form using short phrases to indicate the anticipated cumulative impact to each target resource and its expected magnitude and probability of occurrence.

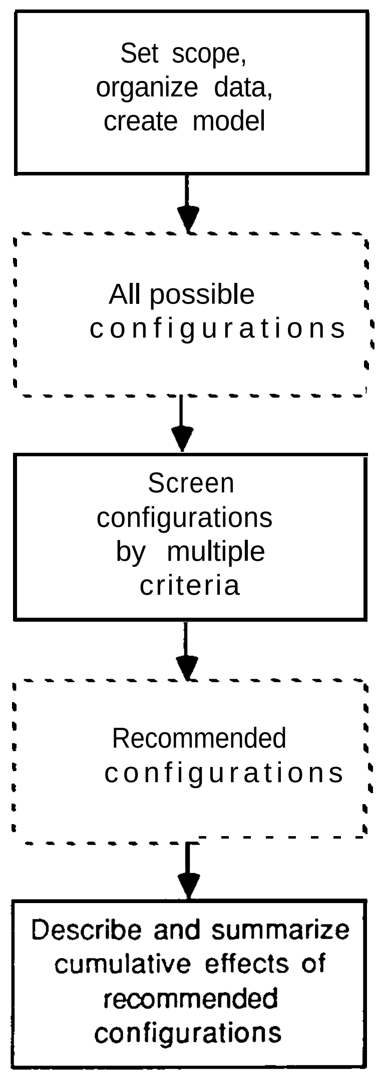


FIGURE 6.2 Flow Diagram of the AMM **Methodology**

6.2.2 Evaluation

This methodology has not been fully applied in any case to date. Parts of it have been used in studies of hydroelectric development in the Snohomish and Salmon River Basins by the Federal Energy Regulatory Commission (FERC). The methodology is, in part, a by-product of these studies and some of its features were developed in response to problems and criticisms experienced by the assessment team. While the methodology is new and lacks established scientific credibility and any agency endorsement, it incorporates established assessment methods such as computer-oriented multidisciplinary team coordination (similar to the AEAM methodology discussed in Sec. 6.1), resource components and indexes (as used by Dee et al. 1972, 1973, U.S. Fish and Wildlife Service 1980), and matrix-based computational algorithms (see, for example, Sondheim 1978).

The AMM methodology was designed to assess the impacts (including interactions) of multiple projects on multiple resources or resource components by using a matrix-oriented format for assembling data into a small number of summary ratings. The relative impact ratings account for both additive and nonadditive effects of the projects in each configuration. However, summary ratings are not aggregated across resources, so no single summary statistic is computed for each configuration of projects.

The cost, data, and time requirements and the predictive capability of the methodology are study-specific since the basic analyses required to develop the impact ratings for each target resource must be determined by individual assessment team members. The cost and time requirements (including use of computer resources) are small for less than 10 proposed projects but rapidly increase for very large studies (14 or more proposed projects).

The major disadvantages of the methodology originate in several procedures used to simplify the assessment process and coordinate information. One of these procedures is the use of a dimensionless scale for evaluative impact ratings and relative cumulative impact. This method of abstraction allows a diverse array of different effects to be compared for various configurations, but is difficult to directly relate to anticipated resource changes. Another important procedure is the assignment of project-interaction coefficients to account for nonlinear accumulation of impacts. Although these coefficients allow nonadditive effects to be incorporated into the estimates of cumulative effects, they require the nonlinear responses of resources to be described. Without good information on resource responses to multiple impacts, the computations must be mathematically simple and will therefore fail to closely parallel reality.

This methodology has been directly linked to the ongoing clustered-impact studies of FERC and other agencies in the Snohomish and Salmon River Basins, although FERC does not support the entire methodology and has only used parts of it in the basin studies. The intense scrutiny and criticisms of these studies by many natural resource agencies make this approach unacceptable for application in the Columbia River Basin without major modification.

6.3 CLUSTER IMPACT ASSESSMENT PROCEDURE

6.3.1 Description

In 1985, FERC prepared an environmental impact analysis for 12 hydroelectric projects in the upper San Joaquin River Basin, California (FERC 1985a). This analysis (described in Cada and McLean 1985) was the first attempt by FERC to assess impacts from multiple hydroelectric projects in a river basin.

In the upper San Joaquin River Basin study, project-specific impacts on each target resource were rated on a scale of 1 to 5 (showing increasing impact severity). These ratings were organized into a resource impact matrix with the rows representing projects and the columns target resource components. A summary column from each resource impact matrix was carried over to a summary matrix, in which the rows represented projects and the columns resource impacts. This summary matrix represented the impacts of the projects without mitigation measures. The process was then repeated with mitigation measures included in the analysis, resulting in another summary matrix, showing impact ratings with mitigation. These two matrices served as the basis for final recommendations of project acceptability.

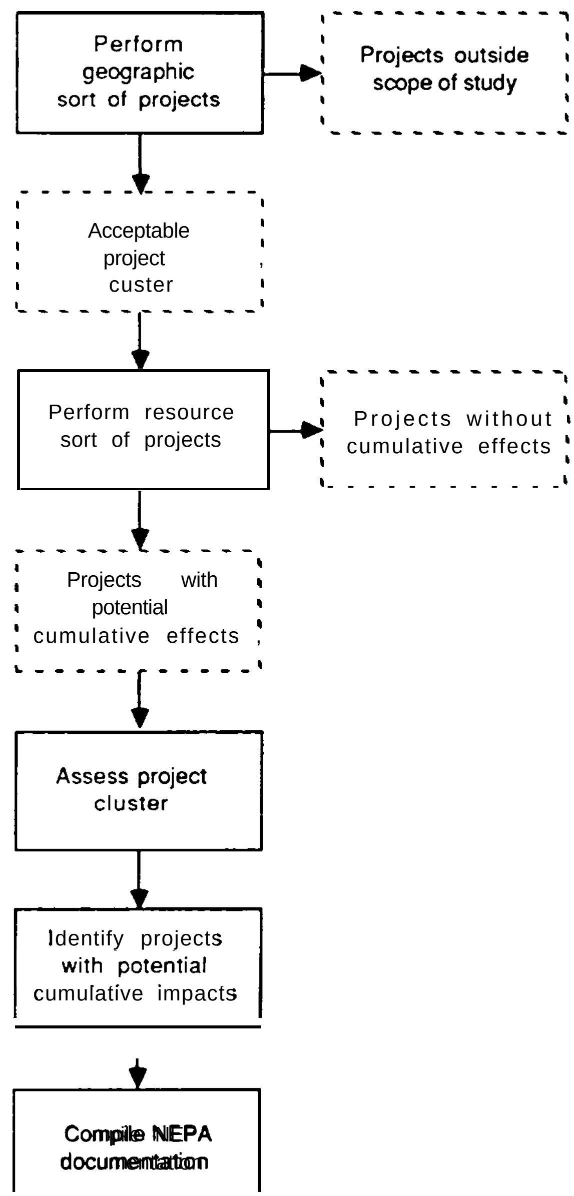


FIGURE 6.3 Flow Diagram of the CIAP

The San Joaquin methodology was subsequently modified and formally proposed by FERC as the cluster impact assessment procedure (CIAP) (FERC 1985b, Russo 1985). The FERC then initiated three more studies, on the Snohomish, Salmon, and Owens River Basins, for initial application of the CIAP.

The CIAP consists of four phases (see Fig. 6.3):

- A geographic sort,
- A resource sort,

- A multiple-project impact assessment, and
- Preparation of an environmental impact statement.

These phases involve identifying a cluster of projects that may have cumulative effects on the environment, sorting through these projects to remove from the study those without potential cumulative effects on specific target resources, and analyzing cumulative effects on target resources for the remaining projects. Impact assessment tec niques include workshops, mapping, matrices, and multivariate statistical analysis.

The geographic sort consists of scoping meetings and a workshop to identify the hydroelectric projects in a cluster, the target resources, and the components of these target resources to be included in the analysis. The resource sort addresses target resource distributions. At this point, projects are dropped from further study if it can be determined that they have no potential for cumulative impact on any target resource. In the muitiple-project assessment phase, the remaining projects are assigned impact ratings for each target resource component. Summary matrices are developed from these impact ratings. Further possible analyses include (1) computing an overall weighted impact value across all target resources, (2) using statistical analyses (factor and cluster analyses) to identify groups of projects with similar patterns of impact, and (3) plotting impact versus energy production.

The three initial applications of the CIAP are still in progress. Draft environmental impact statements were issued in 1986 for all three basins being studied. However, the procedures employed in the Snohomish and Salmon River Basins studies significantly deviated from those originally outlined by FERC. Consequently, these two studies are discussed separately in Sec. 6.10. The Owens River Basin study was conducted by Oak Ridge National Laboratory and generally followed the CIAP, including the time schedule and workshop series. However, no statistical analysis of impact ratings was performed. The total anticipated resource loss for all seven proposed projects in the Owens River Basin was computed as a simple sum of all project-specific losses, which became the basis for discussing the cumulative impacts of all proposed projects. The final recommendation was based on summary matrices with and without mitigation measures.

6.3.2 Evaluation

The methodology is very time-consuming because of the emphasis on workshops and scoping meetings to identify the major study components. There are no specific data requirements, although the validity of study conclusions is sensitive to data quality and quantity. Impacts are not accumulated for combinations of proposed projects; therefore, cumulative effects are not evaluated. On a project-specific basis, anticipated impacts are aggregated across target resources to produce a weighted summary impact value. These values are combined into an evaluation of environmental impact as a function of power production. Target resource aggregation and power/impact plots are highly controversial and would be difficult to defend.

The potential advantages of the CIAP include the generous opportunities for agency and public input during the several scheduled workshops and meetings. The methodology is systematic and relatively simple except for some statistical techniques intended for use in the multiple-project assessment phase. The methodology is flexible since it does not restrict the types of resources (species or habitats) that can be addressed. Flexibility in data analysis and impact prediction is considerable, but the results must reported in terms of impact ratings (in matrix format), which are difficult to use in determining impact significance.

The CIAP has been criticized by a variety of agencies and its initial applications have been highly controversial. Also, the technical staff conducting these applications modified the multiple-project assessment phase. These alterations were substantial in the cases of the Snohomish and Salmon Rivers Basin studies where entirely different analysis techniques were developed. Consequently, the methodology as originally proposed remains largely untested and does not have scientific credibility.

One of the major criticisms of the CIAP relates to its role in hydropower regulation. Nonhydroelectric land use effects are not incorporated in the analysis on an equal basis with hydropower effects. The analysis tends to become oriented around the proposed hydroelectric projects rather than the natural resources of the basin being studied. For this reason, the CIAP has little potential for use in basinwide planning.

6.4 HABITAT EVALUATION PROCEDURES

6.4.1 Description

The habitat evaluation procedures (HEP) were developed to assess the effects of many kinds of developments on fish and wildlife habitats and to incorporate this information in planning, evaluation, and decision-making processes (U.S. Fish and Wildlife Service 1980). The methodology was first proposed by Daniel and Lamaire (1974) for evaluating water resource development projects. Although the HEP were originally developed for assessing impacts to terrestrial, estuarine, and freshwater systems, the U.S. Fish and Wildlife Service recommends using, instead, the instream flow incremental methodology (see Sec. 6.5) when the main concerns are changes in streamflow, channel morphology, or water quality (Armour et al. 1984). Similar methodologies have been developed by various state and Federal agencies (Hamor 1974, Willis, 1975, U.S. Army Corps of Engineers 1980, Davis and Arney 1981).

The HEP compare habitat quantity and quality before and after a project or management practice is implemented. The habitat information needed can usually be obtained from aerial photographs or resource maps (e.g., of conifer tree canopy or grass cover), although field work may sometimes be necessary. A habitat evaluation is generaily conducted for several species of interest within a project area. Habitat evaluations for different species can be weighted to account for differences in management priorities.

The methodology is based on the use of simple models or equations to provide estimates of habitat quality (Schanberger et al. 1982). Several predetermined, species-specific habitat parameters are measured and used to rate habitat types according to their suitability to support populations of the species of interest. These indexes (fractional values from 0 to 1) are aggregated by an equation to give a single habitat suitability index (HSI) for each species and habitat type. The HSIs are multiplied by the habitat acreage to give the total number of habitat units (HU) in the study area for each species. Habitat units are, therefore, a measure of both habitat quality and quantity. A list of species for which HSI models have been developed is presented in Roberts et al. (1985).

The HEP involve the following steps. First is planning, which includes (1) choosing an evaluation team, (2) scoping the project proposal, (3) delineating the study or project area boundaries, (4) collecting information and maps, (5) mapping cover types, (6) selecting species for evaluation, (7) selecting or developing HSI models for those species, and (8) selecting appropriate inventory sampling and techniques. Next, the current (i.e., preproject) habitat conditions for each species are determined, and future (i.e., postproject) habitat conditions are predicted for various target years. Finally, future conditions (measured in HU) are compared for various project alternatives, including a no-action alternative.

The HEP can also be used to analyze the effectiveness of mitigation strategies or to propose compensation for habitat degradation or loss. Multiple projects can be accommodated by performing iterations of the procedure to add various projects and project combinations to the evaluation.

6.4.2 Evaluation

The HEP were specifically developed to determine the effects of development projects on the quality and quantity of fish and wildlife habitats. The species are chosen by consensus before the evaluation is begun. The HEP can be used for any type of development that involves land disturbance. Although never intended for cumulative impact assessment, HEP could be used for this purpose by performing iterations of the procedures for each project added to the basin analysis. However, to do so would be awkward and time-consuming for more than a few projects. The HEP could easily incorporate numerous proposed projects into a single analysis, but this would obscure each project’s contribution to the cumulative effects.

For each species, several techniques can be used (e.g., matrices, models) to aggregate the large amount of information produced by the evaluation of each habitat type and species under both pre- and postproject conditions. A single value combining the HSIs for all habitat types can also be obtained for each species. No attempt, however, is made to derive a composite score that combines the effects on the habitats of several species.

The HEP methodology was designed to be easily implemented with minimum demands on personnel, cost, time, and data. Although some field work is usually necessary, most data can be obtained from aerial photographs or maps. Models have been developed for a large number of species, but these necessarily blur important site-specific or regional relationships between species and habitats. The validation of these models is for the most part incomplete, and they may need considerable refinement to increase their reliability (Lancia et al. 1982, Cole and Smith 1983). Habitat suitability models could be developed and validated specifically for wildlife species in the Columbia River Basin. Lancia et al. (1982) and Farmer et al. (1982) provide guidelines for model development and validation.

6.5 INSTREAM FLOW INCREMENTAL METHODOLOGY

6.5.1 Description

The instream flow incremental methodology (IFIM) is composed of a number of hydrologic and hydraulic models. The hydrologic models use an historical data base of stream flow and runoff records to predict flow under various conditions. The hydraulic models use information on depth, velocity, substrate size, cover, and temperature to estimate the availability of suitable habitats for different fish species at various discharge rates. The IFIM was developed to coordinate these divergent models. The theory and application of IFIM have been described by Bovee (1982) and summarized by Stalnaker (1979, 1982). The IFIM has been widely used to identify instream flow requirements for aquatic biota in assessments of hydroelectric and other water resource developments.

The IFIM indirectly evaluates water management practices by quantifying the effects of altered stream flow regimes on fish habitats (Armour et al. 1984); it does not directly evaluate the effect of projects on fish populations. The IFIM is designed to help formulate instream flow recommendations; assess the effects of altered stream flow regimes, habitat improvement projects, and mitigation proposals; and assist decision makers in negotiating releases from existing storage projects.

The major assumptions of IFIM are as follows:

- Depth, velocity, substrate, and cover are the most important habitat variables that affect the distribution and abundance of fish in a stream,
- These same variables are independent in their effect on the distribution and abundance of fish,
- Stream channels are not altered by changes in the flow regime,
- Streams can be modeled on the basis of one or more representative sample reaches, and
- A positive linear relationship exists between estimates of usable habitat area and fish standing stocks or habitat use.

The IFIM consists of (1) project scoping, (2) field measurements of stream hydraulic conditions, (3) simulations to predict flow conditions, and (4) models of habitat preferences to describe the effect of flow on fish habitats (see Fig. 6.4). Project scoping identifies the purpose and bounds of the study, the area and species to be studied, the current habitat quality and quantity in the study area, and species use of the area. Field measurements address channel, physical, and chemical characteristics. Simulations are then conducted of the spatial distribution of hydraulic depth, velocities, substrate, and cover and of the temporal distribution of temperature and chemical constituents. Habitat evaluation criteria are then applied for each species and life stage of interest, and the usable area of the stream is then determined for each life stage of each species under various flow regimes or channel conditions (Stalnaker 1979).

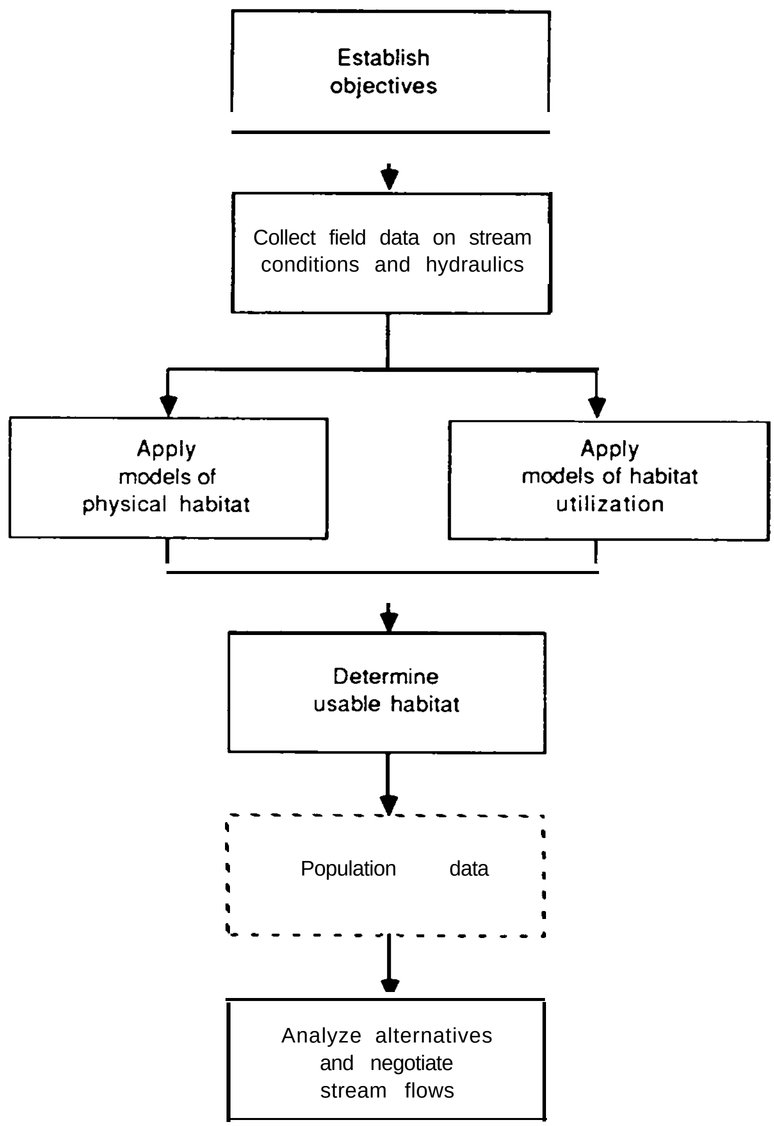


FIGURE 6.4 Flow Diagram of the IFIM

6.5.2 Evaluation

The IFIM was developed to assess the effects of water resource projects on the quality and quantity of habitats available to stream fish. It is closely allied to the HEP (see Sec. 6.4), which are used to perform a similar function but emphasize wildlife. The IFIM, like HEP, was not originally intended to assess cumulative impacts but could do so by iterations with various numbers and combinations of projects in a single basin. Development-induced changes in hydrologic and hydraulic variables could be used as input into models that predict the additional effects of other projects.

The IFIM is data-intensive and requires an extensive field effort to quantify variables at the project site. In addition, the methodology requires extensive computer modeling and can be quite expensive. The models are used to determine the area of usable habitat within the stream for each species and life stage. There are no mechanisms for directly assessing flow alteration effects on multiple species or for considering other effects of hydroelectric development (those unrelated to flow changes). Basinwide analyses have not been formally included in the IFIM, so interactions among multiple projects are not presently analyzed to produce results on total effects within a basin. If multiple IFIM analyses are used to assess multiple projects, the overall analysis could be very complex. As with the HEP, the IFIM uses habitat suitability models for each species, which may be inappropriate for site-specific conditions and reduce the accuracy of predictions. In addition, recent reviews of the methodology have revealed biases in the model used (Annear and Conder 1984, Mathur et al. 1985).

The IFIM is currently used widely in the Northwest for evaluating hydropower impacts on fish, especially salmonids. It has the advantage of being a familiar assessment, management, and planning tool. However, its usefulness for basinwide planning is limited by its data requirements, narrow scope in terms of the species considered and effects analyzed, and inability to incorporate wildlife analyses. The final product of IFIM studies, weighted usable area/discharge curves, may be complex and require additional analyses to be used to basinwide planning and regulation.

6.6 INTASA METHODOLOGY

6.6.1 Description

An assessment methodology was developed by INTASA Inc. as part of a study by the U.S. Army Corps of Engineers on the nationwide potential for hydropower development (INTASA 1981). The purpose of the methodology is to provide relative estimates of cumulative effects within river basins. Simple impact indexes are used to evaluate and compare regional differences in hydropower development. A thorough assessment of the cumulative effects of nationwide hydropower development was said to be beyond the scope of the study.

The major steps of the INTASA methodology are as follows:

- Estimate the potential for hydropower development in a given river basin,
- Identify the affected resources in the basin,
- Estimate the degree of dependency of these resources on the hydrologic regime,
- Estimate the rate of change of these resources with additional hydropower development,
- Calculate impact indexes, and
- Evaluate the significance of the resources lost.

The INTASA report provides general guidelines for carrying out each of these steps. Completion of this evaluation for a region gives a broad overview of the affected resources and status of development in each basin.

Four indexes in the INTASA methodology can be used to compare the relative level of hydropower effects in different river basins. These indexes have wide applicability to regional planning studies, require little new information, and can be easily calculated. They include (1) hydropower development potential, (2) control of stream flow, (3) degree of impoundment, and (4) amount of land inundated. The first index relates the actual amount of hydroelectric generation to the theoretical potential of the basin. The second index measures the degree of alteration of natural stream flow that results from hydropower development and is calculated as the percentage of average annual stream flow that is impounded. The third index measures the percentage of the river's length that is impounded. The fourth index is measured as the percentage of the drainage basin area encompassed by reservoirs. This last index is used primarily to estimate cumulative effects on wildlife, land use, and cultural resources. The indexes for control of stream flow and degree of impoundment are used primarily to estimate cumulative effects on fish, recreation, water quality, and aesthetics.

6.6.2 Evaluation

The INTASA methodology was developed specifically for the National Hydroelectric Power Assessment Study. It was used to compare levels of development and environmental impact among river basins in the United States rather than to evaluate proposed hydroelectric projects within a basin. The methodology does not evaluate direct quantitative information on affected resources but uses very crude indexes to determine the degree of hydrologic change that occurs in a river as a consequence of hydropower development. It addresses only additive cumulative effects to gross hydrologic characteristics. The INTASA methodology has no predictive capability for specific resources of interest (e.g., salmonids, threatened and endangered species).

The INTASA methodology is very economical to implement because it relies on four easily calculated indexes of hydropower impact. It has some value for hydropower planning, if cumulative effects on fish and wildlife or other biota are not of major interest. It is not a useful approach to resource management or hydropower regulation where the details of hydropower effects on fish and wildlife are required to adequately assess impacts and mitigation measures.

6.7 LINEAR PROGRAMMING

6.7.1 Description

Linear programming and related methods (successive linear programming, compromise programming, optimization, dynamic programming, and others) have been applied to environmental planning (e.g., Cohon and Marks 1975), fishery management (e.g., Waters 1975), and other multi-objective problems. In addition, linear programming methods have been used to find optimal levels of river basin development (Duckstein and Opricovic 1980) and optimal modes of hydropower operation (Grygier and Stedinger 1985).

Linear programming is a mathematical method for finding an optimal solution to any problem that can be expressed as a formula with a series of variables under different levels of constraint. Consequently, linear programming and related mathematical methods are commonly referred to as optimization techniques. A simple example of an optimization problem that could be solved by linear programming is:

Find the largest value of F where $F = 0.4X_1 + 0.3X_2$

if $X_1 + X_2 < 400$, $2X_1 + X_2 < 500$, $X_1 > 0$, and $X_2 > 0$.

An optimal solution for F would require finding the values of X_1 and X_2 that satisfy the stated constraints and yield the largest value of F. More-complex mathematical methods can accommodate nonlinear functions, layers of optimizations, probabilities, and stochastic variables.

The key characteristic of linear programming and related methods is the optimization of one variable at the cost of all others within some bounds. For example, Grygier and Stedinger (1985) applied linear programming to optimize energy production given a series of constraints on water supply, minimum flows, reservoir levels, and other parameters. This application is an example of a situation where one goal (i.e., maximizing energy production) is affected by limitations imposed by other goals (i.e., desired ranges of reservoir and stream volumes). Essentially, this case is similar to basinwide resource management in that numerous competing resource management objectives interact to limit each other. For cumulative assessments of hydroelectric development, optimization methods can similarly be used to identify the optimal level of development given constraints based on resource management objectives (e.g., salmon escapement, sediment concentrations, recreational opportunities). However, the properties and dynamics of the environmental system must be known.

6.7.2 Evaluation

Linear programming and related optimization methods provide a basis for assessment and planning directed at maximizing some resource quantity or yield. The mathematics explicitly incorporate multiple resources, one of which could be the level of hydroelectric development. Accumulation of effects, or changes in resource states, are directly addressed since the objective of the approach is to find levels for each resource that would maximize some objective. The key is to have a clear item or resource to maximize (or minimize, depending on how the problem is stated). In basin planning of hydroelectric development, generating capacity could be used as a maximized variable, but this would frame the problem as a tradeoff between power and the environment, a potentially unwise approach. One disadvantage is that resource levels and constraints need to be expressed numerically, which could be difficult. Different resources are not directly aggregated, but are combined mathematically to produce an optimal multiple-resource function.

The linear programming approach is mathematically complex and can be very expensive in terms of computer costs, which are determined by the size of the problem. These costs increase rapidly as variables are added. However, the most expensive and time-consuming task may be the data collection and research needed to develop the optimization algorithms. The data collected must also be made consistent in terms of units and quality. The sensitivity of this mathematical approach to actual environmental effects and conditions will depend primarily on the quantity and quality of the data used in the problem and the algorithm development.

In sum, although linear programming has had, and will have, a useful role in basin planning and management, its mathematical complexity and the need for quantifying resource variables severely limit its scope of applicability. At present, its use may not be justified or fully workable given the current extent of resource understanding and data availability. Linear programming should perhaps be considered as only one of many tools available to assist in basinwide assessment and planning.

6.8 MULTIATTRIBUTE UTILITY ANALYSIS

6.8.1 Description

Multiattribute utility analysis is a sophisticated, versatile, and documented methodology for planning and decision making. It has been described in several books (e.g., Keeney and Raiffa 1976, Zeleny 1982) and papers (e.g., Bell 1979, Howard 1980, Keeney 1982), and has appeared in the fisheries management literature (e.g., Hilborn and Walters 1977, Keeney 1977, Healy 1984). In addition, the methodology has been applied to impact assessment and environmental planning (e.g., Keeney and Robilliard 1977, Bakus et al. 1982, Gershon and Duckstein 1983). It provides a logical and explicit framework for coordinating relevant data to evaluate stated alternatives or options.

In impact assessments, utility analysis is primarily used for evaluating the relative desirability (utility) of alternatives or project sites. The methodology is particularly appropriate for situations involving multiple resource management objectives, uncertainty about possible impacts, and value judgments regarding impact importance. The basic components of a utility analysis are as follows:

- Structuring the problem,
- Specifying a value structure,
- Rating or quantifying environmental impacts, and
- Identifying a preferred alternative or option.

The initial task is to identify a set of alternatives and multiple objectives (target resources). The second task, specifying a value structure, requires a numerical rating of the relative importance of each objective or potentially impacted resource. In other words, the assessment team must specify how important each resource is. Next, each alternative is rated or quantified with regard to its impact on the target resources being considered. The techniques used to quantify individual impacts are not specified in utility analysis; they remain the responsibility of technical specialists. Finally, the reiative utility (desirability) of each alternative is computed based on a linear formula that can be summarized by:

$$U_i = \text{sum of all } (W_j \cdot P_{i,j} \cdot u_{i,j})$$

where:

U_i = utility of alternative i,

W_j = importance weight for resource j,

$P_{i,j}$ = probability of a specific impact occurring, and

$u_{i,j}$ = standardized rating of the impact of alternative i on resource j.

The preferred alternative would be the one with either the largest or the smallest value of U_i, depending on the signs of the values representing impacts. The formula just stated is a simple example pertinent to an impact assessment. Many variations and extrapolations are possible.

Although utility analysis has not been directly used for cumulative impact assessment studies, past applications to siting studies and regional impact assessment suggest ways in which it could be modified for such studies on a basinwide basis.

6.8.2 Evaluation

Utility analysis provides a means for identifying options with the greatest utility given a specified set of values and objectives. Consequently, utility analysis is primarily a decision-making procedure. The output is a single summary statistic for each option, developed from a large amount of input data and ratings. Many variations of the basic procedure are available, allowing flexibility. For a multiproject analysis, the alternatives compared would consist of various project configurations. A distinctive feature of utility analysis is the aggregation of resource information into a single index of relative utility. Also, substantial effort must be directed toward explicitly formulating a value structure consisting of the relative importance of each resource. This step could be highly controversial. Political considerations may make it difficult to develop an acceptable and defendable value structure, which could eliminate utility analysis as a possible tool for environmental planning.

Utility analysis is easily learned, used, and explained except for a few mathematical details. With software commonly available for utility analysis, problems can be rapidly executed and repeated simulations made to evaluate various scenarios. The methodology can accommodate several types of data and considerations, although the need to reduce all information to a single utility index may present some restrictions. The sensitivity of the procedure to the level of detail important to natural resource development would depend on the data adequacy, validity, and precision. Since utility analysis is analogous to modeling, a detailed understanding of the problem and the relevant factors affecting the outcome is required to adequately develop a model.

Utility analysis can be very useful in helping decision makers formalize and understand the implications of their objectives and values. The methodology does not give any “correct” answer but helps users structure the problem and maintain consistency. It can also help illustrate to others why a particular alternative was chosen. Probably the single largest impediment to the use of utility analysis is the requirement that values be presented in numerical form.

6.9 SNOHOMISH GUIDELINES

6.9.1 Description

In 1984, guidelines for evaluating hydropower projects in the Snohomish River Basin, Washington, were developed by a group consisting of the U.S. Fish and Wildlife Service, the Washington Departments of Fisheries and Game, the National Marine Fisheries Service, and the Tulalip Indian Tribe. These guidelines were developed because the agencies and tribe felt that traditional techniques for project evaluation were not adequate for predicting either project-specific impacts or cumulative effects from multiple projects. Their goal was to establish a procedure for hydropower project assessment in the Snohomish River Basin that would prevent the incremental loss of habitats and populations (Stout 1985).

The guidelines enable all potential hydropower sites in the basin to be ranked by their suitability for development, based on criteria relating to (1) the location of anadromous fish barriers, (2) the quantity and quality of existing and potential fish and wildlife habitats, (3) slope and soil stability, (4) fish stocks of special significance, (5) water supplies for existing or proposed fish hatcheries, (6) wetlands, (7) old-growth timber, (8) riparian habitats, (9) threatened or endangered species, and (10) other sensitive habitats or species. These criteria are used to place sites into three categories: (1) those with insignificant project-specific and cumulative effects, (2) those with significant project-specific and cumulative effects that could be fully mitigated, and (3) those with significant project-specific and cumulative impacts that could not be mitigated.

The assessment process consists of eight steps:

- Define the geographic area and activities to be evaluated.

- Identify the resources of concern and establish management goals for each resource.

- Identify the parameters to be evaluated, assessment methods, and thresholds of significance. The guidelines recommend assessment methods.

- Describe project impact zones in terms of the magnitude, extent, and duration of an impact.

- Evaluate the significance of project-specific impacts relative to established thresholds.

- Evaluate the significance of cumulative effects, in areas of project impact zone overlap, relative to established thresholds.

- Develop follow-up studies, performance standards, and contingency plans.

- Make recommendations based on the above evaluation.

The project impact zone is a description of the magnitude, area1 extent, and duration of a physical impact. Project-specific effects are assessed within the impact zone of each project, and effects due to interaction among projects are assessed in areas where the impact zones of two or more projects overlap. Cumulative effects in the basin are assessed by combining project-specific effects and effects due to interaction within project impact zones. These cumulative effects are compared to predetermined thresholds to determine their significance.

The Snohomish guidelines have been used in the assessment of two hydroelectric projects in the Snohomish River Basin (Twin Falls and Weeks Falls). In both cases, agencies were concerned about the potential for erosion, sedimentation, and interruption of bedload transport. Predictions, based on established thresholds and studies, were made on the significance, extent, and duration of the impacts. As **a** result, project designs were modified to minimize the expected impacts, and approval was given to both projects.

6.9.2 Evaluation

The Snohomish guidelines were intended to ensure that fish and wildlife management issues would be incorporated into hydropower planning in the Snohomish River Basin. The goal stated in the guidelines is to classify the potential hydropower sites in the basin as to their suitability for development based on their potential impacts to fish and wildlife. Detailed project-specific studies provide the data base for assessment activities.

The guidelines are intended to address cumulative impact issues with regard to multiple projects and multiple resources in the basin, but they take a relatively simplistic approach to this task. Cumulative effects are predicted only in the areas where project impact zones overlap. Project impact zones may be difficult to delineate, however, and no guidance is given for defining these zones. The concept of project impact zones unrealistically forces the classification of locations into either affected or unaffected categories. No systematic method is proposed for accumulating the effects of multiple projects on a resource or for aggregating the effects of multiple projects on several resources. The lack of a systematic framework for accumulating and aggregating impacts substantially reduces the utility of the guidelines as a cumulative effects assessment methodology.

The final product of an assessment based on the guidelines would be a list of projects that meet or fail to meet the significance thresholds established for either project-specific or cumulative impacts to each parameter of interest. The utility of the guidelines for hydropower planning is enhanced by the early incorporation of input from resource agencies and developers. Although the guidelines call for a classification of all potential sites within the basin, they could be used to evaluate a much smaller group of projects.

6.10 SNOHOMISH AND SALMON RIVER BASINS METHODOLOGY

6.10.1 Description

In 1985, FERC began applying the CIAP (see Sec. 6.3) to assess the cumulative impacts of multiple hydroelectric projects in two Pacific Northwest river basins. Argonne National Laboratory was contracted to execute the analysis and subsequently made substantial changes in the methodology. The resulting studies included many, but not all, aspects of the AMM methodology (see Sec. 6.2). Consequently, these river basin studies are described as a separate methodology. This review is based on the draft environmental impact statements for the Snohomish and Salmon River Basins (FERC

1986a, 1986b) and therefore may differ from the final procedures, as described in the final environmental impact statements.

In general, the Snohomish and Salmon River Basins studies applied the AMM methodology within the framework of the CIAP schedule. As in the CIAP, a geographic sort workshop was held to identify target resources and hydroelectric projects for study, and was followed by a resource sort workshop to identify target resource components and impact criteria. Then, data on impacts were analyzed in a multiple-project assessment phase. Concurrent with these meetings and activities, a series of CIAP tasks (announcements, public hearings, scoping, etc.) was executed to satisfy NEPA requirements, including requirements for certain environmental documents. Deviation from the CIAP primarily occurred in the multiple-project assessment phase. Instead of the CIAP factor/cluster analyses, which are intended to identify projects with similar types of impacts, cumulative impacts were evaluated according to the AMM methodology, using impact ratings, interaction coefficients, and matrix algebra.

One major distinction between the Snohomish and Salmon River Basins studies and the AMM methodology involves the approach taken to develop impact ratings and interaction coefficients. Impact ratings and interaction coefficients were generally developed on a qualitative, likelihood-of-impact basis rather than on an approximation of resource responses to environmental change, as recommended in the AMM method. This qualitative, probability-oriented approach was used due to deficiencies in the available data and in the general scientific understanding of resource impact responses. Other differences from the AMM methodology were (1) the inclusion of projects in the basin studies that might be unacceptable on a site-specific basis and (2) the use of power production as a consideration in making final recommendations. These differences were related to the CIAP approach and were partially maintained throughout the studies.

6.10.2 Evaluation

Many of the advantages and disadvantages of the AMM method (see Sec. 6.2) and the CIAP (see Sec. 6.3) pertain to the Snohomish and Salmon River Basins methodology, since elements of both of these methodologies were used. In addition, other strengths and weaknesses emerged from the application of this combined methodology to a data-limited study.

The reliance on likelihood-of-impact criteria rather than on anticipated biological responses to effects was due to constraints on data availability that could not be remedied during the analysis. Nevertheless, this practice weakens the predictive capability of the method and makes determinations of impact significance difficult.

The methodology is oriented toward the regulation of hydroelectric development rather than management of river basin resources. The reason is that the methodology was developed for, and applied to, an environmental regulatory process. No single-project assessment preceded the cumulative analysis, so proposed projects were included that were unacceptable on a single-project basis. This complicated the task of identifying the limits of basinwide impact and determining cumulative impact significance. Power production was considered along with environmental effects in the development of recommendations. This type of benefit-cost tradeoff also complicates cumulative effects analysis by mixing economic values with natural resource values.

The Snohomish and Salmon River Basins methodology accumulates impacts of multiple projects on the basis of ratings of many individual resources and components. No aggregation occurs across resources, so results and recommendations are presented for multiple parameters rather than as a single summary index. The actual analysis phase was completed in less than two months after all of the input data were assembled. The analysis was relatively simple to execute for the Snohomish River Basin study, which covered seven proposed projects, but it became somewhat difficult and time-consuming for the Salmon River Basin study, which covered 15 proposed projects. Future experience with these ongoing studies may determine more about the advantages and disadvantages of the methodology.

6.11 SNOHOMISH VALLEY ENVIRONMENTAL NETWORK

6.11.1 Description

The College of Forest Resources, University of Washington, developed a methodology for evaluating the physical, economic, and environmental consequences of alternative land use decisions and development-induced impacts (Schrueder et al. 1976). The methodology has been named the Snohomish Valley environmental network (SVEN) since it was developed and tested for the Snohomish River Basin in Washington. The SVEN methodology allows users to maintain basin-level data on a variety of environmental resources and predict future basinwide conditions from changes in environmental conditions.

The methodology is oriented around a central model called the information system, which contains summary data on resources within 40-acre units, called cells. The data for each cell consist of values for 47 items, including stream characteristics, soil type, history, and resource uses. This centralized resource information and cell format identifies the SVEN methodology as a data base and mapping system. Input to the information system comes from any of 200 subsystems used to generate new data and simulate cell entries under new conditions. These subsystems cover meteorology, timber harvesting, wildlife, hydrology, recreation, and other topics related to land use (University of Washington 1974).

At the time the SVEN methodology was documented (Schrueder et al. 1976), the fish and wildlife subsystem was composed of only one model covering a single species (black-tailed deer). The absence of other models was attributed to the lack of appropriate research results on other species. While the fish and wildlife subsystem was poorly developed, the environmental subsystem contained simulation models covering meteorology, hydrology, and atmospheric parameters. Also, a recreation subsystem contained data on 11 recreational activities. This subsystem can report the supply of recreational opportunities as well as predict recreational demand based on regression relationships with as many as 75 environmental predictor variables.

6.11.2 Evaluation

The SVEN methodology provides a framework for maintaining a geographic data base, consisting of cell-by-cell data that can be aggregated to assess basin-level conditions. The methodology can accommodate simulations of multiple projects and multiple land use changes, and it explicitly addresses multiple resources since separate models are developed for each resource of interest. Site-specific environmental changes can be summarized and reflected in basinwide resource statistics. Changes in resource conditions are not aggregated across resource categories except in cases where the values for one resource are used as the input values for another resource model. Depending on the resource models employed, interactions among multiple projects may or may not be represented in basinwide resource totals.

Maintenance of a SVEN-type system is not expensive or time-consuming. The vast majority of costs are associated with data collection and resource monitoring. However, initial system development could be moderately expensive and time-consuming. Once completed, the system could be easily expanded or modified to improve the resource models. Therefore, this methodology is flexible in many ways, although resource models must remain consistent for the basin. Sensitivity to detail will depend primarily on the resource model capabilities and degree of resolution (cell size for data units).

The SVEN methodology can provide a convenient and readily usable means of obtaining basin-level summary resource values given a series of changes imposed by hydroelectric development. Hence, simulation of different project development scenarios is possible. The methodology also provides useful information for licensing purposes and resource management planning. The critical aspects of the methodology with respect to usefulness and validity are the accuracy of the resource models and the input data. If the resource models are insensitive to the effects of hydropower development or are based on weak data and assumptions, this methodology will not be useful in basin planning or hydropower regulation.

6.12 SWAN RIVER ASSESSMENT METHODOLOGY

6.12.1 Description

The Montana Department of Fish, Wildlife, and Parks developed a methodology to determine the potential cumulative effects of small-scale hydropower development on both migratory and nonmigratory trout populations. Using this methodology, Leathe and Enk (1985) evaluated the potential cumulative effect of 20 proposed small-scale hydropower projects on bull, cutthroat, and eastern brook trout in the tributaries of the Swan River, Montana.

The general methodology involves five steps (see Fig. 6.5):

- Inventory existing resources and uses,
- Identify key environmental effects and develop response models,
- Determine single-project effects,
- Establish and simulate development scenarios, and
- Accumulate effects.

For the Swan River study, detailed information was collected on fish populations, angler use, economic values, habitats, land-type composition, and land use to include in a

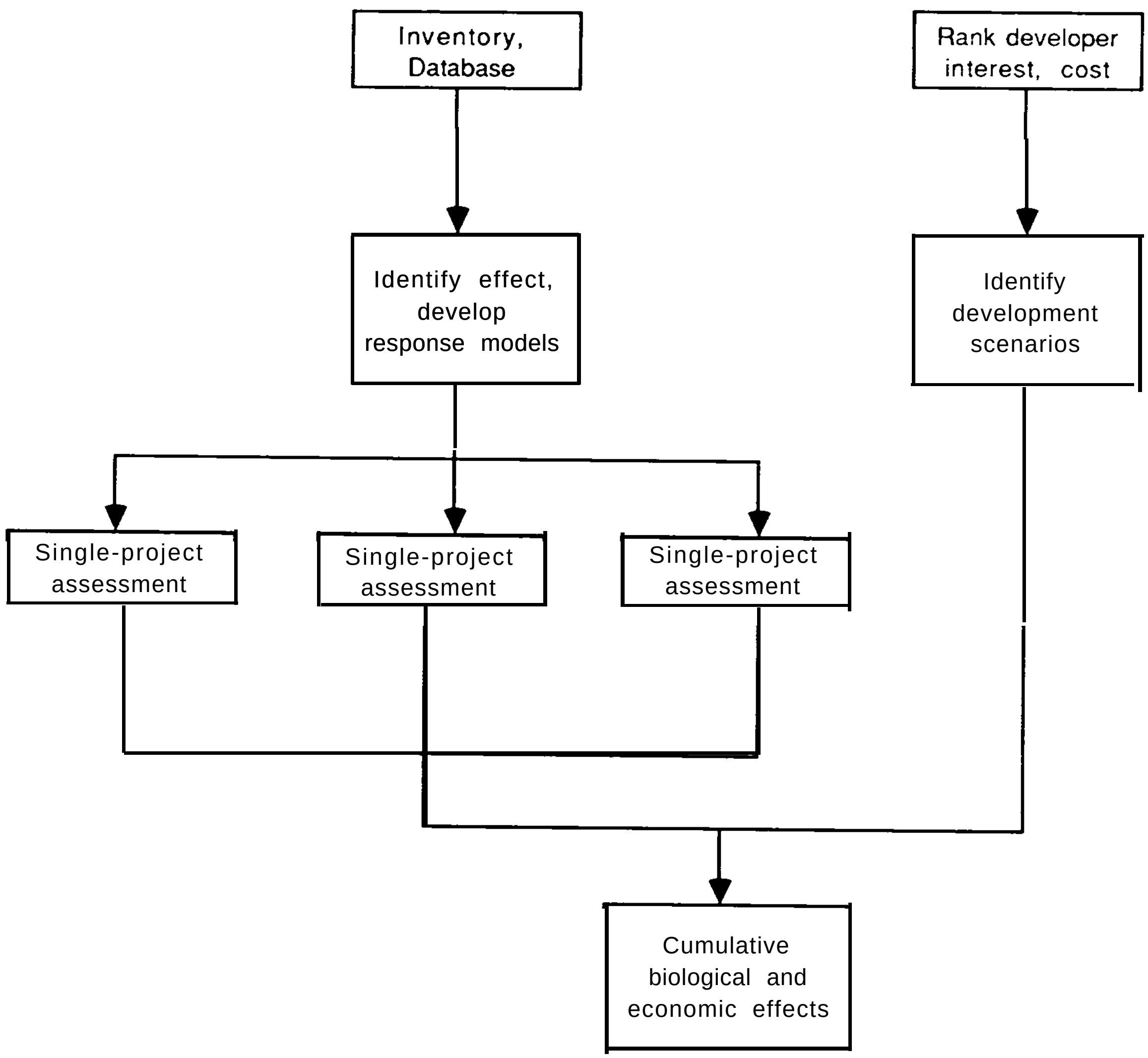


FIGURE 6.5 Flow Diagram of the Swan River Assessment Methodology

basinwide data base. These data were collected firsthand using a variety of field techniques, including ground and aerial surveys of streams, spawning surveys, creel censuses, and an economic survey.

The following types of hydropower effects were then identified as the most important to be evaluated in the Swan River study: (1) fish species and their life history, (2) dewatering, (3) upstream passage, (4) downstream passage and turbine mortality, (5) sedimentation, (6) temperature alterations, and (7) gas supersaturation. Dewatering and sedimentation were the only impacts, however, that were used to predict the response of fish populations to various levels of hydropower development.

The impact of individual projects was determined using a computer program to simulate instream flow (Nelson 1984) and the U.S. Forest Service's sediment model for the Flathead National Forest. Regression techniques were used to assess the empirical relationship of various stream bed conditions to trout population density. Projects were then ranked according to the developers' interest in them and their relative cost. The cumulative biological and economic effects of several hypothetical development scenarios, ranging from four projects built over a 4-year period to 20 projects built in one year, were evaluated based on output from the simulation models. The interacting effects of logging operations in the basin were also evaluated for individual and multiple projects.

6.12.2 Evaluation

The Swan River methodology was developed to assess the impacts of hydropower development on fish resources in the Swan River Basin, Montana. In its present form, it has limited applicability to other areas of the country or to assessments of the impacts of development on wildlife. However, the Swan River methodology has merit as an approach to cumulative impact assessment.

The Swan River methodology was designed to incorporate information on multiple resources (several fish species) and multiple projects (20 in total). It uses sophisticated modeling techniques to accumulate and aggregate data and predict fish population densities for a variety of development scenarios that represent varying numbers and combinations of projects and construction schedules. Its first application was greatly simplified because a decision was made to deal only with two fish species and two potentially cumulative effects on fish populations. The methodology is very data-intensive and in its first application required detailed studies on the life history requirements of the two species of interest and their response to several degrees of stream dewatering. In general, once such studies are completed for a basin or subbasin, they could be used in combination with a regional species population data base to model resource population responses to development.

The Swan River methodology has sufficient flexibility to ailow evaluation of different development schemes. Its output, the percentage loss of fish, can be easily understood and is useful for planning purposes. If data were available or could be collected, the methodology could be used for hydropower regulation and applied to fisheries management. Expanding the scope of the methodology to include more species and more effects would enhance its applicability but would require the development of new models.

6.13 TARGET APPROACH

6.13.1 Description

Dickert and Tuttle (1985) conducted a study of the cumulative effects of urban development in a California coastal watershed where the major environmental concern was wetlands protection. Although the study specifically addressed cumulative impact issues, it was intended for project-specific regulatory uses. The methodology involved identification of target environmental conditions for subbasins, which were then used to determine project acceptability on a case-by-case basis. The primary issue addressed by the study was the effect of land development on estuarine sedimentation.

Research was conducted to obtain data on hydrological parameters, upland erosion and deposition, land use over time, and area of rapid erosion for each land use. Based on the research results, an indicator (percentage of land disturbed) was identified as a standard by which to classify existing conditions in each subbasin, i.e., as either below or above the target levels. This particular indicator reflected estuarine sedimentation rates and was selected because it could be easily obtained by local government agencies responsible for land use regulation. The purpose was to ensure that attention to cumulative effects could be incorporated into the permitting process for individual projects. That is, before a permit could be issued, existing subbasin conditions had to be checked against the target levels. If existing conditions were above target levels, additional development would not be permitted until conditions declined below the target levels. If existing conditions were less than target levels, further development would be permitted.

The authors of this methodology distinguish between threshold criteria and target levels. Threshold criteria were found to be difficult or impossible to identify before development occurred, difficult to defend in terms of the technical data available, and lacking in terms of a scientific or theoretical basis. Target levels are not based on anticipated system responses to a change (impact), but instead on the observed historical relationship between land development and watershed characteristics. Consequently, target levels are simply planning goals based on past experience with different degrees of development and land disturbance.

6.13.2 Evaluation

The target approach has several advantages over other methodologies. Cumulative impacts are addressed in a procedure that is compatible with traditional project review and licensing procedures. The methodology is initially time-consuming and expensive because a comprehensive research program must precede any project assessments. However, once research is completed, reliance on simple indicators and target levels minimizes long-term costs and time constraints. The details of the estuarine sedimentation study do not directly apply to hydroelectric planning and regulation, but the general methodology can be used.

The methodology depends on thorough research to identify a simple and easily obtained environmental quality indicator. The sensitivity of this indicator will depend on the quality and quantity of the information used to derive it. Accumulation of impacts will depend on how the indicator variable is selected or defined. A variable should be identified that can represent cumulative impacts to the resources of interest. Once an indicator is identified, a target level must be developed based on management objectives.

The disadvantages of the target approach are (1) the need to aggregate all resource information into one or a few indicators and (2) the inflexibility in terms of altering procedures for individual cases. Since the indicator and target levels are used as criteria for project approval, their validity and credibility will be subject to heavy scrutiny.

The target approach is best suited to situations where a clear and readily obtainable indicator can be found and where impacts decline over time or can be effectively mitigated. The use of an indicator was developed to allow project approval when basinwide conditions improve or recover from past development. The indicator is expected to be monitored and to change **as** development activities change. This presents a problem for many hydropower impacts that cannot be expected to decline over time or be mitigated.

6.14 TRINITY LAKES ASSESSMENT METHODOLOGY

6.14.1 Description

The Trinity Lakes cumulative assessment methodology was developed to assess the effects of 12 proposed small-scale hydropower projects in the Trinity Lakes area of California (Oscar Larson and Associates undated). The methodology uses ad hoc and descriptive techniques and relies heavily on professional judgment rather than on quantitative analyses. The basic approach of the methodology is illustrated in Fig. 6.6.

In the Trinity Lakes study, sensitive resources and specific parameters for each resource were identified for all projects. The sensitive resources included mule deer, wildlife and plant species with special status (e.g., threatened and endangered species), wildlife habitats, fisheries (including kokanee salmon, rainbow trout, and brown trout), recreation, timber, historical and archaeological resources, water quality, and community services. A baseline assessment was then conducted using existing data.

The geographic area to be considered for each resource was determined and a simple conceptual model was constructed to describe the relationship between the resource and the factors affecting it. These descriptive models were specific to the projects considered in the study and are not applicable to other development scenarios. Cumulative estimates (frequently worst-case) were made of the amount of habitats affected by all hydropower projects. The effects of different numbers or combinations of projects were not analyzed. The study assumed that a decline in habitat quality or quantity would result in a proportional reduction in population numbers. Impact significance was determined by comparison to a previously established threshold or by reliance on professional judgment. Several mitigative measures were assessed for their effectiveness in protecting the resources affected by development, and preferred measures were proposed.

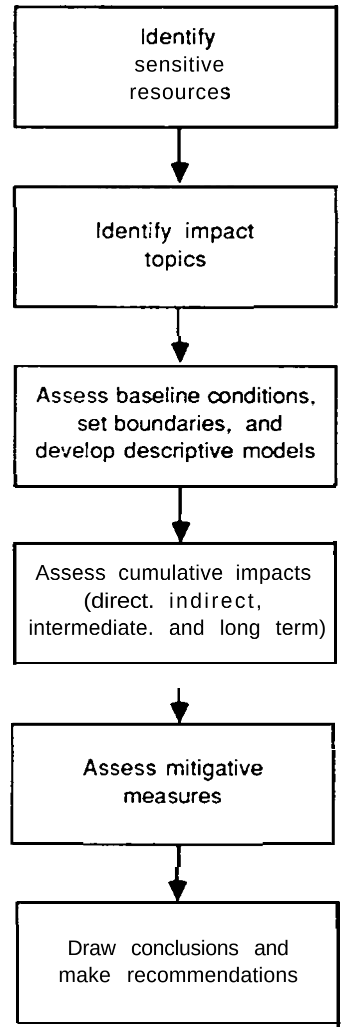


FIGURE 6.6 Flow Diagram of the Trinity Lakes Assessment Methodology

6.14.2 Evaluation

The Trinity Lakes methodology was developed for a specific application and was cumulative in the sense that the total effects of all 12 projects in the Trinity Lakes region of California were considered as a unit. However, different numbers and combinations of the proposed projects were not assessed.

The methodology does not provide a systematic framework for accumulating and aggregating impacts. The estimated losses of habitat that resulted from each activity or project were simply added, **but not** accumulated for multiple projects or aggregated for different types of activities. As with other ad hoc approaches to impact assessment, this methodology is simple and inexpensive to execute because it has low demands for data and time. It is not very useful for planning or resource management, however, because it does not allow the relative impact of projects to be compared or 00 different development scenarios to be evaluated.

6.15 WATER RESOURCES ASSESSMENT METHODOLOGY

6.15.1 Description

The water resources assessment methodology (WRAM) was developed by Solomon et al. (1977) to assess the environmental, economic, and social effects of water resource developments of the U.S. Army Corps of Engineers. After reviewing 54 methodologies. the authors decided to develop a new methodology that drew various techniques from existing methodologies, largely from the environmental evaluation system (Dee et al. 1973). The methodology has been used in Louisiana and other places to assess flood control alternatives (Richardson et al. 1978). The basic steps of WRAM are outlined in Fig. 6.7.

The WRAM uses a multidisciplinary approach. Effects are assessed separately in four “accounts”: environmental quality, national economic development, social well-being, and regional development. Each account contains a number of variables to be evaluated. For example, the environmental quality account includes the variables of water quality and water quantity, which are used to assess the effects of projects on fish. A list of variables is included in the WRAM report but this list can be revised for each assessment study. Pairwise comparisons are used to assign weights or coefficients of relative importance to variables. The variables to include in an assessment and their relative weights are determined during scoping sessions for each study.

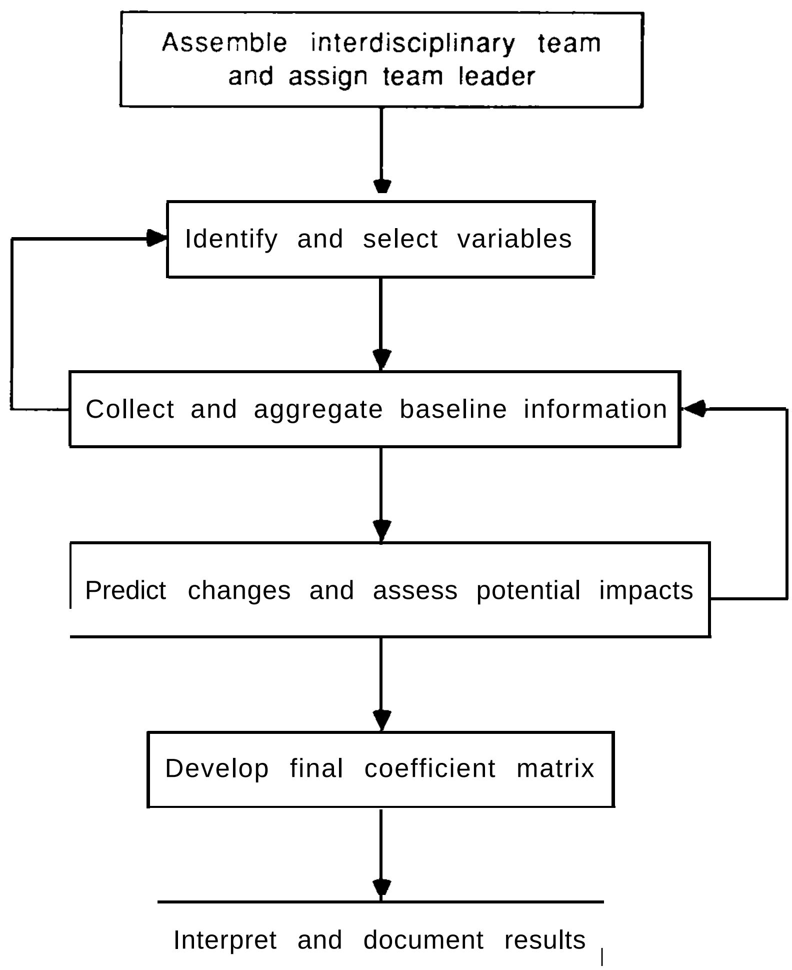


FIGURE 6.7 Flow Diagram of the WRAM

The WRAM encourages the use of existing data during the accumulation of baseline information. Where data gaps exist, however, a data-gathering program may be initiated. The weighting scheme can be used to set priorities at this stage of the assessment process.

Where possible, impact prediction is based on quantitative models, but qualitative data can be incorporated as well. Consideration should be given to the type of effect (direct or indirect), the area expected to be affected, and the effect's timing, duration, probability of occurrence, and reversibility. The effects of each project alternative are scaled (using fractional values from 0 to 1) according to their relative importance, which is determined by a variety of techniques, including examination of the functional relationships between the value of each variable and an environmental quality index.

The results are evaluated and interpreted using a series of matrices that represent each project's impact on all the variables of interest in each of the four accounts (see the example in Table 6.1). The final coefficient matrices are derived by multiplying the relative-importance coefficients by the impact scales for each variable and for each project alternative. The relative impacts of projects can be evaluated by comparing the summary values for each project. In the example presented in Table 6.1, the no-action alternative is the most desirable one, followed by plan C.

6.15.2 Evaluation

The WRAM was designed to examine the effects of water resource development on many resources, including fish and wildlife. It is similar to multiattribute utility

TABLE 6.1 Example of a WRAM Final Coefficient Matrix

		Relative Impact of Plan				Final Coefficient Matrix[b]			
Variable	RIC[a]	No Action	A	B	C	No Action	A	B	C
1	0.35	0.50	0	0.33	0.17	0.18	0	0.11	0.06
2	0.35	0.33	0.50	0	0.17	0.11	0.18	0	0.06
3	0.15	0.17	0.33	0	0.50	0.02	0.05	0	0.08
4	0.15	0.33	0	0.17	0.50	0.05	0	0.02	0.08
Total	-	-			0.36	0.23	0.13	0.28	

[a]RIC = relative-importance coefficient.

[b]Each value is derived as follows: RIC x relative impact.

Source: Solomon et al. 1977.

analysis in many respects (see Sec. 6.8), and the evaluation of that procedure (in Sec. 6.8.2) applies to WRAM as well. The WRAM was not developed as a cumulative impact assessment technique, but its ability to incorporate a wide variety of data and resources makes it potentially useful for this purpose. As used to date, the methodology is capable only of analyzing the effects of individual proposed actions. However, it could be used to evaluate various numbers and combinations of projects (i.e., development scenarios) by accumulating data on single-project effects, aggregating these effects across resources, and then comparing the results for each development scenario.

The WRAM is highly flexible in terms of the types of data that can be used and the types and numbers of projects, impacts, and resources that can be considered. The cost of using WRAM, in terms of money, personnel, and time, depends on several factors, including the adequacy of the existing data base and the techniques used to predict impacts on specific resources (e.g., predictive modeling, geographical information systems).

The WRAM simplifies the evaluation process by providing a structured framework for handling the large amounts of data that accumulate when many projects and resources are being considered. This makes the methodology useful for basinwide planning, hydropower regulation, and resource management. In order to implement WRAM in the Columbia Riven Basin, some technique for predicting impacts on each resource would have to be identified. If quantitative models were chosen, these would have to be developed for the resources and impacts of interest.

6.16 WETLAND FUNCTIONAL ASSESSMENT METHODOLOGY

6.16.1 Description

The wetland functional assessment methodology was developed for the Federal Highway Administration (FHWA) to assess the impacts of highways and associated facilities on wetlands (Adamus 1983, Adamus and Stockwell 1983). The methodology provides a rapid assessment procedure for screening the functional values of wetlands, estimating the level of impact of a highway project on a given wetland, and analyzing mitigation proposals. The method has been used by the FHWA, U.S. Army Corps of Engineers, U.S. Environmental Protection Agency, and numerous state agencies.

The wetland functions considered in the methodology include (1) groundwater recharge and discharge, (2) flood storage and desynchronization, (3) shoreline anchoring and dissipation of erosive forces, (4) sediment trapping, (5) nutrient retention and removal, (6) food chain support, (7) habitats for fisheries, (8) habitats for wildlife, (9) active recreation, and (10) passive recreation and heritage value. The methodology consists of three procedures:

- Threshold analysis, which estimates the likelihood that a single wetland is of high, moderate, or low value for each function;

- Comparative analysis, which estimates whether one wetland is likely to be more important than another for each function; and

- Mitigation analysis, which evaluates the efficacy and cost-effectiveness of various mitigative measures.

Each of these analyses is based on a series of simple questions. Some simple field observations of the site are generally required, but much of each analysis can be done without field work. Each wetland is evaluated in terms of its current (preproject) state and its predicted condition after project completion. The analyses examine the effects of a project on the entire basin and on the smaller wetland impact area.

The fish and wildlife portion of the analysis is based on general habitat characteristics but consideration can be given to the requirements and preferences of individual species. The analysis of fish habitats includes water quality, water quantity, cover, and substrate. The analysis of wildlife habitats focuses on the requirements of waterfowl and other birds that are strongly dependent on wetlands, and includes habitat diversity and the availability of food and cover.

6.16.2 Evaluation

The wetland functional assessment methodology was developed to evaluate impacts to wetlands and cannot incorporate effects on other environmental systems that may be of interest with regard to hydropower development. This is a serious drawback for its application to hydropower planning and regulation. The methodology has several attributes that are advantageous, namely, simplicity, modest data requirements, and rapid execution.

This methodology was not intended as a cumulative assessment procedure and does not evaluate the effects of multiple projects. However, it does consider numerous wetland functions or resources. Environmental data on impacts to a specific resource are not accumulated in the usual mathematical sense, but rather are used to answer a large number of questions that, in their entirety, provide an evaluation of a project's relative impact on that resource. An overall evaluation of a project's effect on all wetland functions is not produced. In practice, the methodology is necessarily subjective and provides limited predictability and resolution of the relative effects of individual projects. In its present form, it has limited utility to hydropower planning, regulation, and resource management.

6.17 COMPARISON OF METHODOLOGIES

The 16 methodologies reviewed in this section fall into two groups. The first consists of methodologies specifically proposed for, or used in, cumulative effects assessments. They are as follows:

1. INTASA methodology,

2. Snohomish and Salmon River Basins methodology,

3. Swan River assessment methodology,

4. Target approach,

5. Trinity Lakes assessment methodology,

6. AMM methodology,

7. CIAP, and

8. Snohomish guidelines.

The first five of these methodologies are well described with published case studies. The other three are recently proposed cumulative assessment methodologies without published case histories.

The second group contains methodologies that were not proposed for cumulative effects assessment but that could be used for that purpose. They are as follows:

1. HEP,

2. IFIM,

3. Wetland functional assessment methodology,

4. AEAM methodology,

5. Linear programming,

6. Multiattribute utility analysis,

7. Snohomish Valley environmental network, and

8. WRAM.

These are all established and recognized assessment methodologies that tend to be supported by a theoretical basis and a published history of application to single-project assessment (i.e., the first three above) or environmental planning (i.e., the last five above).

Most of the methodologies are capable of dealing with multiple resources and multiple projects or can be expanded to do so. The Snohomish guidelines, Snohomish Valley environmental network, and the Swan River and Trinity Lakes methodologies address multiple resources but have no procedures for aggregating information across them in order to derive general conclusions or recommendations. Most of the methodologies accumulate the effects of multiple projects in some way, although the HEP, IFI.& and Snohomish guidelines lack specific accumulation procedures. Linear programming and multiattribute utility analysis require modification to accumulate effects from multiple projects. The AEAM methodology is unique among those reviewed since it does not specify any particular assessment procedures. Consequently, for any application of the AEAM methodology, the accumulation and aggregation of effects will depend on the assessment staff's decisions.

Application of the methodologies can vary substantially in terms of simplicity (including costs and time), depending on the characteristics of the assessment (e.g., data availability, field research conditions, complexity of project proposals). The target approach and the AEAM, AMM, and wetlands functional assessment methodologies were designed to be simple, according to their documentation. The HEP, Snohomish guidelines, and wetlands functional assessment methodology have the clearest procedures although implementation of all of the steps may be difficult in some cases. In general, there is an inverse relationship between methodological simplicity and sensitivity to detail. The methodologies that appear to be most involved and complex (IFIM and the Swan River methodology) also seem to be the most able to identify small incremental effects on resources. On the other hand, those that seem easiest to use (the amm, INTASA, and wetland functional assessment methodologies, HEP, the target approach, and WRAM) also appear unable to evaluate small incremental effects, and their ability to predict the occurrence of such effects is minimal.

Flexibility is an important practical characteristic of any methodology intended for wide application. The AEAM methodology is clearly the most flexible since the assessment is largely shaped by the participants. Most methodologies are moderately flexible since they provide only a general structure to the assessment with actual resources and resource components specified on a case-by-case basis. However, the target approach and the INTASA, Snohomish and Salmon River Basins, and water resources assessment methodologies were developed for specific cumulative assessment situations and do not provide options for altering the considerations included in the assessment.

All of the methodologies reviewed could be used to address cumulative effects in some form. However, the methodologies vary with regard to their applicability to regulatory action, planning, and resource management. The AMM, CIAP, Swan River, Snohomish and Salmon River Basins, Swan River, and Trinity Lakes assessment methodologies were specifically developed for licensing hydroelectric projects in cases where cumulative effects on fish and wildlife are the major regulatory issue. The HEP and IFIM are used in regulatory decision making that involves fish and wildlife habitats and various types of developments. Linear programming, multiattribute utility analysis, the Snohomish Valley environmental network, and the target approach are oriented toward planning but were not developed for situations involving fish, wildlife, or hydroelectric projects. The AEAM methodology is very effective for ongoing resource management since monitoring and strategy refinement are major methodological characteristics.

None of the 16 methodologies appears entirely adequate for assessing the cumulative effects of hydroelectric development in the Columbia River Basin. Although some methodologies have very desirable capabilities, they also have serious weaknesses and limitations. However, some methodologies could be used as part of a larger methodology designed specifically for cumulative assessment in the Columbia River

Basin. An effective and comprehensive methodology for cumulative assessment appears to require a recombination of techniques from existing methodologies and the development of new techniques.

6.18 REFERENCES

Adamus, P.R. 1983. A method for wetland functional assessment. Vol. II: FHWA assessment method. FHWA-IP-82-24. Federal Highway Administration, Washington, D.C.

Adamus, P.R. and L.T. Stockwell. 1983. A method for wetland functional assessment. Vol. I: Critical review and evaluation concepts. FHWA-IP-82-23. Federal Highway Administration, Washington, D.C.

Annear, T.C. and A.L. Conder. 1984. Relative bias of several fisheries instream flow methods. North American Journal of Fisheries Management 4:531-539.

Armour, C.L., R.J. Fisher, and J.W. Terrell. 1984. Comparison of the use of the habitat evaluation procedures (HEP) and the instream flow incremental methodology (IFIM) in aquatic analyses. FWS/OBS-84/11. U.S. Fish and Wildlife Service, Western Energy and Land Use Team, Fort Collins, Colo.

Bain, M.B., J.S. Irving, R.D. Olsen, E.A. Stull, and G.W. Witmer. 1986. Cumulative impact assessment: evaluating the environmental effects of multiple human developments. ANL/EES-TM-309. Argonne National Laboratory, Argonne, Ill.

Bakus, G.E., W.E. Stillwell, S.M. Latter, and M.C. Wallerstein. 1982. Decision making: with applications for environmental management. Environmental Management 6:493-504.

Bell, D.E. 1979. Consistent assessment procedures using conditional utility functions. Operations Research 27:1054-1066.

Bisset, R. 1980. Methods for environmental impact analysis: recent trends and future prospects. Journal of Environmental Management 11:27-43.

Bovee, K.D. 1982. A guide to stream habitat analysis using the instream flow incremental methodology. Instream Flow Information Paper 12. FWS/OBS-82/26. U.S. Fish and Wildlife Service, Western Energy and Land Use Team, Fort Collins, Colo.

Cada, G.F. and R.B. McLean. 1985. An approach for assessing the impacts on fisheries of basinwide hydropower development. Pages 367-372 in Proceedings of the Symposium on Small Hydropower and Fisheries, May 1-3, 1985, F.W. Olson, R.G. White, and R.H. Hamre, eds. American Fisheries Society, Bethesda, Md.

Cohon, J.L. and D.H. Marks. 1975. A review and evaluation of multi-objective programming techniques. Water Resources Research 11:208-220.

Cole, C.A. and R.L. Smith. 1983. Habitat suitability indices for monitoring wildlife populations: an evaluation. Transactions of the North American Wildlife and Natural Resources Conference 48:367-375.

Daniel, C. and R. Lamaire. 1974. Evaluating effects of water resource developments on wildlife habitat. Wildlife Society Bulletin 2:114-118.

Davis, S.E. and K.S. Arney. 1981. Computer-assisted spatial analysis as applied to deer management in Tennessee: a case history. Tennessee Valley Authority, Office of Natural Resources, Norris, Tenn.

Dee, N., J. Baker, N. Drobny, K. Duke, I. Whitman, and D. Fahringer. 1972. Environmental evaluation system for water resource planning. Battelle Columbus Laboratories, Columbus, Ohio.

Dee, N., J. Baker, N. Drobny, K. Duke, I. Whitman, and D. Fahringer. 1973. An environmental evaluation system for water resource planning. Water Resources Research 9:523-535.

Dickert, T.G. and A.E. Tuttle. 1985. Cumulative impact assessment in environmental planning: a coastal watershed example. Environmental Impact Assessment Review 5:37-64.

Duckstein, L. and S. Opricovic. 1980. Multiobjective optimization in river basin development. Water Resources Research 16:14-20.

Everitt, R.R. 1983. Adaptive environmental assessment and management: some current applications. In Environmental Impact Assessment. PADS Environmental Impact Assessment and Planning Unit, University of Aberdeen, United Kingdom. Martinus Nijhoff Publishers, Boston.

Farmer, A.H., M.J. Armbruster, J.W. Terrell, and R.L. Schroeder. 1982. Habitat models for land use planning: assumptions and strategies for development. Transactions of the North American Wildlife and Natural Resources Conference 47:47-56.

Federal Energy Regulatory Commission. 1985a. Final environmental impact analysis of small-scale hydroelectric development in selected watersheds in the upper San Joaquin River Basin, California. FERC/EIA-001. Federal Energy Regulatory Commission, Office of Hydropower Licensing.

Federal Energy Regulatory Commission. 1985b. Procedures for assessing hydropower projects clustered in river basins: request for comments. Federal Register 50:3385-3403.

Federal Energy Regulatory Commission. 1986a. Salmon River Basin, fifteen hydroelectric projects: Idaho. FERC/DEIS-0044. Federal Energy Regulatory Commission, Office of Hydropower Licensing.

Federal Energy Regulatory Commission. 1986b. Snohomish River Basin, cluster impact assessment procedure: Washington. FERC/DEIS-0042. Federal Energy Regulatory Commission, Office of Hydropower Licensing.

Federal Energy Regulatory Commission. 1986c. Owens River Basin, seven hydroelectric projects: California. FERC/DEIS-0041. Federal Energy Regulatory Commission, Office of Hydropower Licensing.

Gershon, M. and L. Duckstein. 1983. Multiobjective approaches to river basin planning. Journal of Water Resources Planning and Management 109:13-28.

Grygier, J.C. and J.R. Stedinger. 1985. Algorithms for optimizing hydropower development. Water Resources Research 16:14-20.

Hamor, W.H. 1974. Guide for evaluating the impact of water and related land resource development projects on fish and wildlife habitat. Soil Conservation Service, Lincoln, Neb.

Healy, M.C. 1984. Multiattribute analysis and the concept of optimum yield. Canadian Journal of Fisheries and Aquatic Science 41:1393-1406.

Hilborn, R. and C.J. Walters. 1977. Differing goals of salmon management on the Skeena River. Journal of the Fisheries Research Board of Canada 34:64-72.

Holling, C.S. 1978. Adaptive environmental assessment and management. John Wiley and Sons, New York.

Holling, C.S. 1982. Science for public policy: highlights of adaptive environmental assessment and management. Pages 78-91 in W.T. Mason, ed., Research on Fish and Wildlife Habitat. EPA-600/8-82-022. U.S. Environmental Protection Agency, Washington, D.C.

Howard, R. 1980. An assessment of decision analysis. Operations Research 28:4-27.

INTASA, Inc. 1981. National hydroelectric power resources study. Vol. VIII: Environmental assessment, Appendix H. U.S. Army Corps of Engineers, Institute for Water Resources, Fort Belvoir, Va.

Kamp-Nielsen, L. 1983. State-of-the-art in application of ecological models to water resources. In W.K. Laurenroth et al., eds., Analysis of Ecological Systems: State-of-the-Art in Ecological Modeling. Elsevier Scientific Publishers, New York.

Keeney, R.L. 1977. A utility function for examining policy affecting salmon on the Skeena River. Journal of the Fisheries Research Board of Canada 34:49-63.

Keeney, R.L. 1982. Decision analysis: an overview. Operations Research 30:803-838.

Keeney, R.L. and H. Raiffa. 1976. Decisions with multiple objectives. John Wiley and Sons, New York.

Keeney, R.L. and G.A. Robilliard. 1977. Assessing and evaluating environmental impacts at proposed nuclear power plant sites. Journal of Environmental Economics and Management 4:153-166.

Lancia, R.A., S.D. Miller, D.A. Adams, and D.W. Hazel. 1982. Validating habitat quality assessment: an example. Transactions of the North American Wildlife and Natural Resources Conference 47:96-110.

Leathe, S.A. and M.D. Enk. 1985. Cumulative effects of microhydropower development on the fisheries of the Swan River drainage, Montana: summary report. Montana Department of Fish, Wildlife, and Parks, Kalispell.

Mathur, D., W.H. Bason, E.J. Purdy, Jr., and C.A. Silver. 1985. A critique of the instream flow incremental methodology. Canadian Journal of Fisheries and Aquatic Sciences 42:825-831.

Nelson, F.A. 1984. Guidelines for using the wetted perimeter (WETP) computer program of the Montana Department of Fish, Wildlife, and Parks. Montana Department of Fish, Wildlife, and Parks, Bozeman.

Oscar Larson and Associates. Undated. Trinity Lakes hydroelectric projects: cumulative environmental impacts report. Oscar Larson and Associates, Eureka, Calif.

Richardson, S.E., W.J. Hansen, R.C. Solomon, and J.C. Jones. 1978. Preliminary field tests of the water resources assessment methodology (WRAM), Tensas River, Louisiana. Miscellaneous Paper Y-78-l. U.S. Army Corps of Engineers, Vicksburg, Miss.

Roberts, T.H., L.J. O'Neil, and W.E. Jabour. 1985. Status and source of habitat models and literature reviews: December 1984. Miscellaneous Paper EL-85-l. U.S. Army Corps of Engineers, Vicksburg, Miss.

Russo, T.N. 1985. Perspectives on analyzing impacts related to multiple hydroelectric development. Pages 346-350 in Proceedings of the Symposium on Small Hydropower and Fisheries, May l-3, 1985, F.W. Olson, R.G. White, and R.H. Hamre, eds. American Fisheries Society, Bethesda, Md.

Schrueder, G.F., K.P. Rustagi, and B.B. Bare. 1976. A computerized system for wild land use planning and environmental impact assessment. Computer and Operations Research 3:217-228.

Shamberger, M., A.H. Farmer, and J.W. Terrell. 1982. Habitat suitability index models: introduction. FWS/OBS-82/10. U.S. Fish and Wildlife Service, Washington, D.C.

Solomon, R.C., B.K. Colbert, W.J. Hansen, S.E. Richardson, L.W. Canter, and E.C. Vlachos. 1977. Water resources assessment methodology (WRAM): impact assessment and alternative evaluation. Technical Report Y-77-l. U.S. Army Corps of Engineers, Washington, D.C.

Sondheim, M.W. 1978. A comprehensive methodology for assessing environmental impact. Journal of Environmental Management 6:27-42.

Stalnaker, C.B. 1979. The use of habitat structure preferenda for establishing flow regimes necessary for maintenance of fish habitat. Pages 321-337 in J.V. Ward and J.A. Stanford, eds., The Ecology of Regulated Streams. Plenum Press, New York.

Stalnaker, C.B. 1982. Instream flow assessments come of age in the decade of the 1970's. Pages 119-142 in W.T. Mason, ed., Research on Fish and Wildlife Habitat. EPA 600/8-82-002. U.S. Environmental Protection Agency, Washington, D.C.

Stout, D.J. 1985. A practical approach to cumulative impact assessment. Pages 373-376 in Proceedings of the Symposium on Small Hydropower and Fisheries, May l-3, 1985, F.W. Olson, R.G. White, and R.H. Hamre, eds. American Fisheries Society, Bethesda, Md.

U.S. Army Corps of Engineers. 1980. A habitat evaluation system for water resources planning. U.S. Army Corps of Engineers, Lower Mississippi Valley Division, Vicksburg, Miss.

U.S. Fish and Wildlife Service. 1980. Habitat evaluation procedures. ESM 102. U.S. Fish and Wildlife Service, Division of Ecological Services, Washington, D.C.

Valiela, D. 1984. Improving predictive performance and usefulness of biological environmental impact assessment: experimental impact studies and adaptive impact assessment. In S.L. Hart, G.A. Enk, and W.F. Hormick, eds., Improving Impact Assessment. Westview Press, Boulder, Colo.

University of Washington. 1974. Models of the forest ecosystem of the Snohomish River drainage basin. College of Forest Resources, University of Washington, Seattle.

Walters, C.J. 1975. Optimal harvest strategies for salmon in relation to environmental variability and uncertain production parameters. Journal of the Fisheries Research Board of Canada 32:1777-1784.

Wathern, P. 1984. Ecological modelling in impact analysis. In R.D. Roberts and T.M. Roberts, eds., Planning and Ecology. Chapman and Hall, New York.

Webb, T.M., C.J. Walters, R.R. Everitt, and N.C. Sonntag. 1986. Final report on the adaptive management workshops for the Northwest Power Planning Council. Environmental and Social Systems Analysts, Ltd.

Willis, R. 1975. A technique for estimating potential wildlife populations through habitat evaluations. Pittman-Robertson Game Management Technical Series 23. Kentucky Department of Fish and Wildlife Resources, Frankfort.

Zeleny, M. 1982. Multiple criteria decision-making. McGraw-Hill, New York.

7 DEVELOPMENT OF NEW CUMULATIVE ASSESSMENT METHODOLOGIES

The review in the previous section of assessment methodologies revealed that each methodology contains at least one feature that limits its usefulness and that none is capable of accomplishing all of the tasks required in a cumulative effects assessment. Therefore, either a new methodology based on a new approach should be developed or the best parts of existing methodologies should be combined into a new methodology.

Early in the study, BPA suggested a new approach that might be useful for assessing the cumulative effects of- hydroelectric development on anadromous fish. This "top-down" approach starts by focusing on a single parameter that reflects the overall condition of the resource and that is directly related to mortality in populations due to hydroelectric development. The parameter identified is the productivity of a fish population as determined from stock/recruitment relationships. Section 7.1 examines the use of stock/recruitment relationships for cumulative assessment.

The existing methodologies that have been used in cumulative effects studies are based on accumulation and aggregation of single-project effects, many of which are small and incremental. This "bottom-up""approach requires careful organization of a great deal of site-specific, population-specific, and project-specific information. Since no existing methodology is satisfactory for this task, a new methodology has been developed that combines the most useful parts of several methodologies. The results of this effort, the integrated tabular methodology (ITM), is presented in Sec. 7.2.

7.1 STOCK/RECRUITMENT METHODOLOGY

This section examines the rationale for using stock/recruitment relationships to assess the cumulative effects of hydropower development and for using a maximum sustained yield (MSY) as a standard for establishing habitat goals. The stock/recruitment model uses the ratio of the number of fish entering a spawning population (recruitment) and the number of fish that spawned in the parent generation (escapement). This recruitment/escapement ratio indicates the potential ability of a population or habitat to produce a sustainable surplus of fish, which is a function of both habitat conditions and the genetic characteristics of a stock.

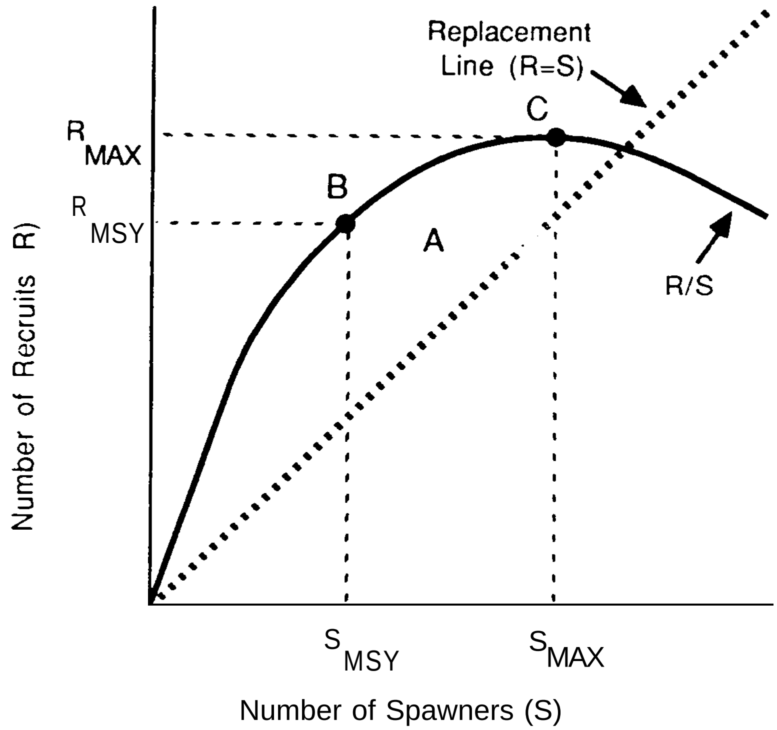
7.1.1 Literature Review

The use of fishery production models to evaluate passage losses due to hydropower has been suggested by several investigators. MacCall et al. (1983), for example, developed a simple method for assessing the long-term significance of fish losses using the Grahamk-Schafer model and the potential yield formula proposed by Alverson and Pereyra (1969). This study treated hydropower projects as analogous to the harvesting of fish, because both reduce the equilibrium level of abundance by removing portions of the population. A similar concept was proposed by Junge (1980).

Hydropower projects also cause modification of spawning, incubation, and rearing habitats. To determine the overall effect on these habitats, Junge and Oakley (1966), Gangmark (1975), and Salo and Stober (1977) compared the production potential of the watershed above a dam before and after the dam's construction. In these studies, productivity was measured in terms of a recruitment/escapement ratio. Thompson (1945) found the productivity ratio, which he termed the "index of success of return," to be closely correlated with passage conditions at Hell's Gate on the Fraser River, and his index of sockeye returns proved useful as a measure of short-term effects. Chapman et al. (1982) analyzed stock/recruitment relationships in Columbia River stocks. They made estimates of ocean catches, but found that the lack of stock identification information made stock-by-stock analysis impossible at that time. Stock/recruitment methods were also used by Irving and Bjornn (1981), Horner and Bjornn (1981a, b, and c), and others to assess the status of specific Columbia River stocks. Whitney and White (1984) discuss the spawner/recruit approach, calling it a direct method of assessment. They conclude that because of a lack of historical data, this method may be difficult to apply to past hydropower impacts on a stock-by-stock basis.

The quantitative relationship between adult offspring (recruits) and those in the parental generation (spawners) has been studied extensively (Ricker 1954, 1958, Beverton and Holt 1957, Chapman 1973, and Cushing 1973; all cited in Ricker 1975). A graph of the relationship between the number of recruits (R) and the number of spawners (S) is called a recruitment curve (see Fig. 7.1). When each generation produces an equal number of the next generation, the recruitment curve intersects the replacement line, where $R = S$. When $R > S$, there is a harvestable surplus production of fish, which is represented by the vertical distance between the replacement line and the recruitment curve. The surplus at the point where this distance is greatest is called the maximum sustained yield (MSY). The spawner escapement level where MSY occurs is referred to as SMSY and results in the production of R_{MSY} recruits. A prevalent management practice is to try to achieve escapements that will maximize harvestable surpluses in the long term. The practice of managing for MSY is due to a general acceptance of the assumption of a predictable spawner/recruit relationship. Because of the large variability in run sizes from year to year, the MSY concept is often considered less than optimal as a tool for short-term management and goal setting (McCarl and Rettig 1983). However, MSY is broadly accepted as an indicator of the long-term surplus production potential.

The spawner escapement level that yields the greatest number of recruits (R_{MAX}) is referred to as S_{MAX}. However, the sustained harvest associated with S_{MAX} is generally less than that associated with S_{MSY}. The term *base run size,* frequently used in reference to mitigation measures for the Columbia River, is equivalent to R_{MAX}, which is the return that would occur when the habitat is used to full capacity. R_{MAX} has been used as a management objective in specific circumstances. For example, steelhead stocks, which are primarily caught at relatively low harvest rates in the upper reaches of rivers by sport fisheries, are sometimes managed to maximize the catch per angler, occurring at R_{MAX}. Also, stocks may be managed for R_{MAX} when MSY is believed to occur close to R_{MAX}, particularly for very productive stocks in a sharply limiting habitat.



A = reproduction in excess of replacement
B = point of maximum sustained yield (MSY)
C = point of maximum production (MAX)

FIGURE 7.1 Typical Recruitment Curve (also called a Ricker curve)

7.1.2 Productivity Ratios as a Measure of Environmental Effects

The productivity ratio (R/S) is the ability of the spawning and rearing habitat to produce new adult fish. The environmental effects of human activities, including hydropower development, on fish habitats should be reflected in that ratio. If the productivity ratio at MSY escapement could be estimated, changes in that ratio over time would be a measure of the effect of environmental changes on the stock. Measuring the resource value in terms of MSY productivity has theoretical advantages over the use of potential run size (R_{MAX} or base run), because the maximum run size may not allow any sustained yield. Productivity measures at other levels of escapement may also have useful assessment potential.

Computation of productivity ratios requires a precise functional definition of recruitment and escapement. For assessment of hydropower development in the Columbia River Basin, one could assume that the entire Columbia River upstream of the Bonneville Dam is one fish production system. If this were assumed, then recruitment and escapement would be evaluated relative to the numbers of fish passing Bonneville Dam, and the productivity ratio would reflect the accumulated effects of all impacts above the dam. Since fishery activities occur both in the river and at sea, the returns to the dam must be corrected for both prior and subsequent harvest impacts. Junge (1980) used a similar means for evaluating base run size and escapement, and Whitney and White (1984a, b, and c) refer to this approach as the “direct” approach. Similar approaches have been suggested by Junge and Oakley (1966), Irving and Bjornn (1981), Horner and Bjornn (1981a, b, and c), and Chapman et al. (1982). The theoretical merits of this type of approach are broadley accepted.

Calculation of the productivity radio involves two major steps: (1) estimating escapement and (2) estimating the recruitment that results from that escapement. Escapement estimates can be derived from ladder counts at Bonneville Dam, but must be corrected for harvest above the dam. The correction will generate a number greater than the reported catch, since adult passage losses before harvest are assigned proportionately to catch and escapement. In most cases, these calculations can be made from catch and escapement reports and dam counts. A further complication in estimating the spawner escapement that produces a given return is the multiple ages at maturity of both chinook and steelhead. Junge and Oakley (1966) assume a constant brood year age composition to derive weighted escapements.

Estimating the recruitment resulting from the escapement requires (especially in the case of fall chinook) accounting for all prior interceptions by remote ocean fisheries, as well as catches in the Columbia River, expressed in terms of adult equivalents. The process for estimating recruitment is complex, and computation of adult-equivalent returns requires computer assistance to account for fishing, natural mortalities, and maturity schedules of the various year classes involved.

Junge (1980) assigned responsibility for dam losses of each upriver stock by dividing the river into production segments separated by dams. He suggests equal sharing of the estimated overall survival losses among all dams negotiated by a stock. However, for the assessment of hydropower impacts, losses should be assigned on the basis of the incremental loss caused by each dam. Certainly, the latter method must be used to forecast the impact of a proposed new development.

7.1.3 Data Requirements

Various authors have noted that the most critical requirement for successful application of the spawner/recruitment approach is adequate data. To determine the extent of the spawner/recruit data base, requests for information were made by phone and/or letter to agencies in the Pacific Northwest. Journals, reports, and unpublished data files were also reviewed. The result was an inventory of information on catch, escapement, run size, redd counts, juvenile outmigration, fishing effort, spawner counts, and dam counts for Columbia River salmon and steelhead. Information was also recorded on fish species, stock, period of record, availability of age data, geographic location of catch, type of fishing gear used, and geographic location of statistical data. In all, 1,859 records were identified (see Table 7.1).

Ocean catch data were found for the major fishing areas and for different fishing gear. This breakdown of information is needed to hindcast the catch of Columbia River stocks from historical ocean catch records. Data on the catch of Columbia River salmon in the ocean are limited to chinook and coho salmon during the period of 1969-1983 and are based on coded wire tag data. This type of catch distribution data is limited, but more data are being developed. The Pacific Marine Fisheries Commission has recently completed an inventory of salmon production by hatchery and wild stocks in order to identify stocks that require fishery contribution data.

TABLE 7.1 Composition of the Data Inventory File for the Stock/Recruitment Methodology

Data Category	No. of Records	% of Total
Catch	742	39.9
Dam count	295	15.9
Effort	32	1.7
Escapement	314	16.9
Juvenile outmigrant	50	2.7
Redd count	132	7.1
Run size	217	11.7
Spawner count	77	4.1
Total	1,859	100.0

Little information on the catch of chum salmon, sockeye salmon, and steelhead trout was found because these species are not intercepted to any significant extent in the ocean. Rather, they are normally caught in rivers near the terminal point of their migration. Data have been recorded for a long period on the catch of salmon and steelhead within the Columbia River, but not on race or catch location until the late 1930s. For coho salmon, catch information by race was not available until after 1970. Little information was found on fishing effort for Columbia River stocks.

A review of the literature on run size indicates that, while data are available, they are not a true estimate of run size. Instead, the data on run size in the Columbia River refer to escapement plus catch within the river and exclude the ocean catch. Thus, data on ocean catch would be used to reestimate run size. Run size is the sum of the total catch, regardless of where it occurs, plus escapement. Run size and age composition are all that are needed to compute recruitment.

Escapement estimates are derived from several sources, such as hatchery returns, redd counts, spawner counts, and dam counts. Data on escapement of nonhatchery chinook salmon, sockeye salmon, and summer steelhead are available since 1936 for many of the major subbasins. The Columbia River Basin contains over 90 salmon and steelhead hatcheries, and escapement data are available for many of the Federal and state hatcheries in Washington and Idaho. In many cases, recording of the hatchery data began in the 1950s, and recording of salmon returns to the Bonneville Pool Hatcheries began in 1938. Counts of salmon and steelhead moving past dams provide the best geographic coverage of the Columbia River Basin. Since 1933, counts have been made at all of the major dams. Fish counts are separated by race in most cases and often by stock as well. The time interval between the completion of Grand Coolee Dam (1941) and McNary Dam (1953) provides a base period when fish were unaffected by further dam construction.

The information needed for a stock/recruitment model would include escapement data for a sequence of years that were relatively free from dam construction, so that this baseline condition could be compared with subsequent reductions in productivity due to hydroelectric development and other events in the basin.

7.1.4 Examples of the Proposed Use of Productivity Ratios in Assessment

Productivity ratios at any level of recruitment have useful assessment potential, because they can be used to determine the point at which a stock can tolerate no further reduction in habitat productivity. Suppose, for example, that a 10% incidental harvest limit is applied to two intercepting fisheries into which a stock was recruited. This would result in a maximum survival to escapement of 0.9 x 0.9, or 0.81, because the effects are multiplicative. The productivity ratio required to maintain the stock at any level of escapement would be the ratio of replacement (1.0) to maximum survival (0.81), which is equivalent to 1.0/0.81, or 1.23.

The productivity rate that produces a maximum sustained yield (P_{MSY}) provides a theoretical means for predicting the impacts of proposed new projects. For example, a two-parameter Ricker curve (such as shown in Fig. 7.1) is of the form

$$R = kSe^{-aS}$$

where a, e, and k are constants, R is recruitment, and S is escapement. For this curve, the parameters S_{MSY} and P_{MSY} completely describe the curve, because e is known and

$$a = \frac{P_{MSY} - 1}{S_{MSY} P_{MSY}}$$

and

$$k = P_{MSY} \cdot e^{(P_{MSY} - 1)/P_{MSY}}$$

This information is all that is necessary to describe the Ricker curve and evaluate the potential effects of changes in environmental conditions on the productive capabilities of the population. If a population currently has a P_{MSY} of 2.74 and the escapement is 80,000 fish, a new hydroelectric facility could cause either productivity or escapement, or both, to change. Suppose that the facility would result in an additional 15% mortality of smolts. This would result in a 15% reduction in the parameter k (Junge 1967), and reduce P_{MSY} to 2.43 and S_{MSY} to 74,200. Surplus productivity (above replacement) would be reduced from 139,000 (i.e., 80,000 multiplied by [2.74 - 1]) to 106,000 (i.e., 74,200 multiplied by [2.43 -1]). This is a decrease in potential surplus production of 23%.

7.1.5 Evaluation of the Methodology

The examples above illustrate how productivity ratios might be used to evaluate the potential long-term effects of development. Other applications might include (1) establishment and monitoring of critical observation thresholds, (2) comparison of the potential effects of different scenarios of hydropower development, and (3) prioritization of mitigation needs.

The stock/recruitment methodology takes a relatively simple, holistic view of a complex system of causes and effects. The methodology is based on the following assumptions:

1. *The MSY productivity ratio is an appropriate measure of the resource value for at least some important upriver stocks.* The productivity ratio concept is distinctly different from other cumulative assessment methods, which emphasize site-specific, case-by-case changes in fish habitats or population size. Productivity ratios can be used to evaluate the long-term trend in the resource value of the fishery and the general condition of the basin for fish production. The results are therefore of great significance in management of basin resources.

2. *Resource reductions due to overfishing and similar sources of direct mortality can, in most cases, be restored if the source of the mortality is reduced.* Stock/recruitment curves imply a continuous relationship between recruitment and escapement, and the methodology is invalid if this assumption is not realistic.

3. *Assessments of overall population loss due to habitat change can be used for management purposes other than assigning responsibility for such loss.* The productivity ratio concept has an important difference from other methods in that it accounts for the impacts of all impacting agents on fish in a single measurement. Such "agents" include the all density-dependent and -independent mechanisms for regulating populations as well as all environmental change, including hydropower development. Potential changes in the productivity ratio could be used to give a quantitative measure of the significance of proposed developments with regard to run size and surplus available for harvest. However, the method cannot partition impacts or assign responsibility for them. The method also cannot be used to monitor the effects of construction and operation of hydroelectric facilities.

The MSY productivity ratio approach cannot measure the actual effect of new hydroelectric developments. The rate of return of fish varies from year to year, even within a homogeneous stock in an unchanged river environment. This variability results from population parameters, the dynamic nature of all of the environments that the fish inhabit, and other factors not yet identified. For this reason, the use of productivity ratios is better suited to evaluation of basinwide, long-term trends. Also, the methodology does not accumulate or aggregate cumulative effects; rather, it evaluates the state of the river basin as a whole.

The methodology would be costly to implement, because it would require a large effort and lengthy period of data gathering and model verification. The stock/recruitment method is meant for continuous application over a long period, during which continual updating of the models would be necessary. However, after the stock/recruitment curves were established, expected changes in productivity could be calculated relatively quickly. The stock/recruitment concept has credibility in the scientific community, but this new use of it would need to be verified by preliminary studies.

Although the data base appears to be large, necessary information is lacking for all stocks and subbasins of the Columbia River. Implementation of the method would require additional effort to improve the data base. The validity of the method depends directly on the reliability of estimates of baseline stock/recruitment conditions, and since those conditions occurred in the past, reliability cannot be improved beyond the capabilities of existing data.

7.2 INTEGRATED TABULAR METHODOLOGY

The alternative to assessing cumulative environmental effects as the change in a single parameter, such as in the stock/recruitment methodology presented above, is to accumulate single-project effects into a total that represents the cumulative effect of all projects together. In this section, a tabular methodology is proposed that integrates assessments of habitat effects and population effects. Methods are included for both accumulating and aggregating impacts. This integrated tabular methodology (ITM) is based directly on the definitions and types of cumulative effects presented in Sec. 5.

A cumulative assessment methodology should be able to account for all of the effects on fish and wildlife that were identified and discussed in Sec. 3. Even in a simple cumulative effects study of three species and three habitats, there are over 40 ways in which effects can be accumulated and aggregated. Not all of these combinations may be meaningful for the study, so only a few of them may be analyzed. Therefore, the ITM provides a flexible framework for accumulating and aggregating single-project effects into cumulative effects. The methodology can be adapted to different conditions in terms of the study scope, data availability, and requirements for impact aggregation.

7.2.1 Steps in the ITM

The primary purpose of a cumulative effects methodology is to organize a large number of simpler impacts into complex, aggregated estimates of cumulative effect. This organization of information must retain a clear concept of the purpose of the cumulative effects study, emphasizing the important cumulative relationships. However, no single method of organization can serve all needs in a cumulative effects assessment due to the diversity of societal institutions calling for cumulative assessment and expectations for continuing human activity and development in the Columbia River

Basin. In each cumulative effects assessment study, seven tasks must be performed (see Fig. 7.2):

- Establish the geographic boundaries and the scope of the assessment,
- Establish information requirements and identify sources of information,
- Design a framework for aggregating and accumulating cumulative effects,
- Develop or recommend models for estimating effects on populations from estimates of effects on habitats,
- Collect information and perform single-project assessments,
- Aggregate and accumulate cumulative effects, and
- Apply results to the planning and regulation of hydroelectric development.

No single existing assessment technique (Sec. 4.2), method (Sec. 4.3), or methodology (Sec. 6) can be used effectively for all of these tasks. However, the AEAM methodology contains the most useful recommendations on how to establish a study scope. Checklists and matrices are the most useful techniques for quantifying the magnitude of environmental effects. The HEP and IFIM are two of the most highly developed methodologies for relating habitat changes to population effects. The Swan River assessment methodology accumulates effects measured in real units, while the CIAP and the AMM methodology accumulate and aggregate effects measured on an evaluative scale. Evaluative techniques are useful for nonquantitative assessments and for expressing the significance of effects to society. Multiattribute utility analysis and linear programming provide means for using qualitative values in decision making.

7.2.2 Establishment of Geographic Boundaries and the Study Scope

In order for cumulative effects study to be effective, a great deal of effort should be spent in establishing geographic boundaries and the study scope, because the decisions made at this point in the cumulative assessment process will directly affect all subsequent steps. The geographic scope of a cumulative effects study can be based on features of the natural environment or on institutional boundaries, such as management areas. How the boundaries are established would depend on the objectives of the study, which should be clearly stated, along with any criteria by which the success of the study will be evaluated. A cumulative effects assessment should not be initiated without a clear definition of the geographic scope, since the framework for accumulating and aggregating effects will depend on which projects and fish and wildlife populations are included in the study.

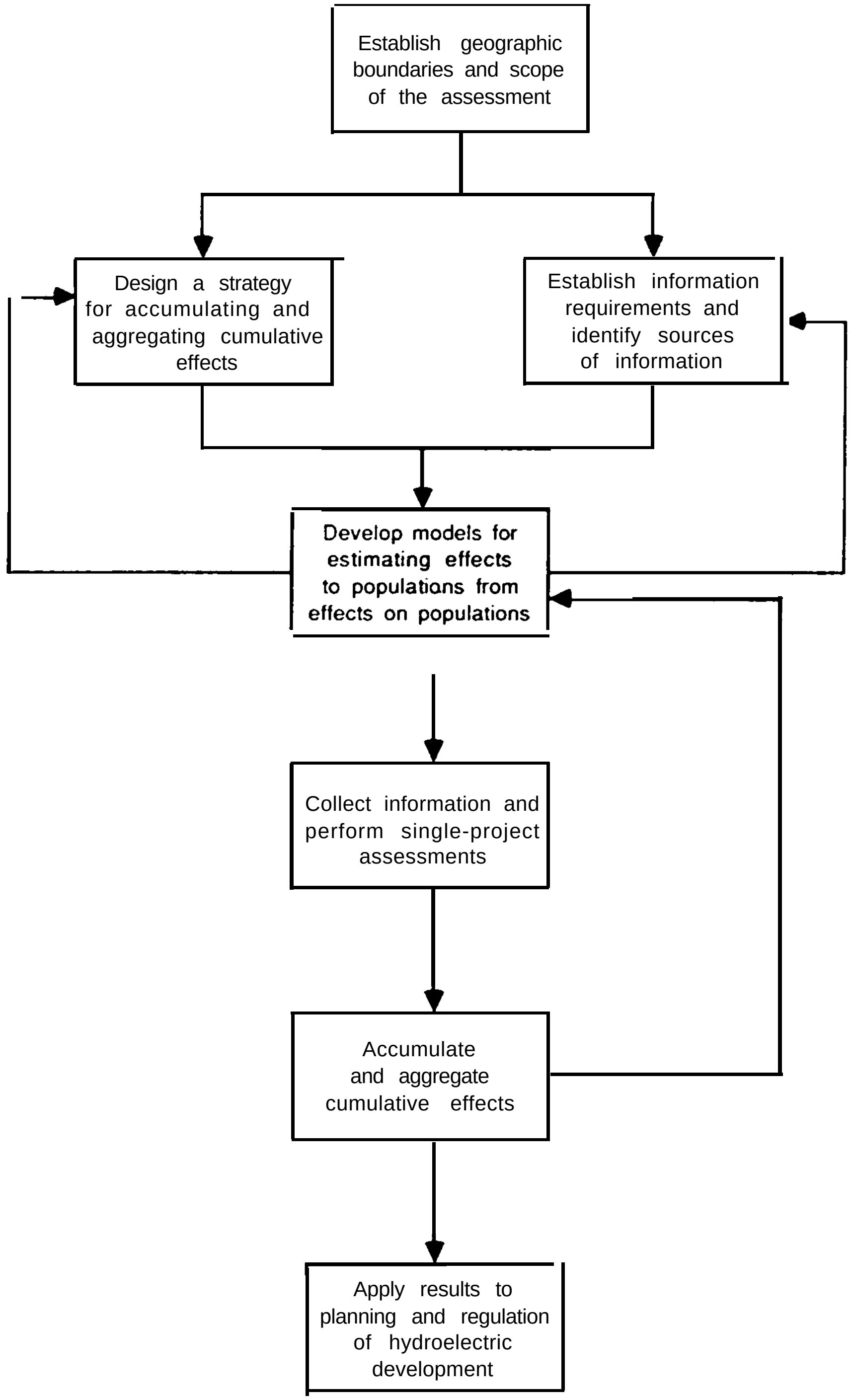


FIGURE 7.2 Flow Diagram of the ITM

After the hydroelectric projects to be included in the study are identified, decisions are made on how to group them. For example, if the study purpose is to evaluate or select among alternative scenarios of hydroelectric development, then these scenarios should also be identified and included in the objectives of the study. Procedures must also be defined for adding or deleting information from the study as time progresses and conditions in the basin change. The study participants should agree on whether development and land-use activities other than hydropower are to be included in the study and, if so, how those activities are expected to interact with hydroelectric projects.

The affected fish and wildlife resources, which are the focus of the study, must also be determined. This step is very important to the selection of an appropriate cumulative assessment methodology. If only one species is the focus of the study, more methodology options exist than if several species are the focus. A cumulative effects assessment for a single species may require less aggregation of data. Initially, all impacts could be transformed into units related to population numbers. Simulation or other quantitative models are more likely to be successful than other methods because there is no reason to compare the impacts with those on different resources of different significance. In a cumulative effects assessment for many species, restrictions on time, effort, and funds are likely to prevent development of complex impact aggregation procedures, such as models, for each species. Also, the relative magnitude and significance of cumulative effects on different species might have to be compared or aggregated into an overall estimate of total cumulative effect.

Ideally, all interested parties in a cumulative effects assessment study will become full participants from the onset, and participants should agree to abide by the collective decisions reached during any negotiations. The AEAM methodology has been very successful for guiding group studies of natural resource management. Decision-making procedures such as those in the AEAM methodology are a necessary part of cumulative assessment. For this reason, the flow of work during the scoping phase of the ITM should be similar to the flow of work in AEAM studies (Fig. 6.1). The study participants should initially meet to determine the overall study scope and assign subgroup tasks, such as (1) establishing information requirements and identifying sources of information and (2) developing or recommending models for estimating effects on populations from effects on habitats for each species included in the study. Next, the subgroups should perform their tasks, after which all study participants should meet again to evaluate the recommendations of each subgroup and design a framework for accumulating and aggregating cumulative effects. Since this framework will determine the final requirements for information and for the models to be used for assessing population effects from habitat effects, these work flow steps should be iterative (Fig. 7.2).

7.2.3 Information Requirements

The structure for impact accumulation and aggregation should not contain elements that are difficult to measure and quantify and for which there are no known sources of data. Also, there should be agreement among the participants that the data sources and methods of data gathering are acceptable. The function of data gathering is very important because enough data of the right type must be available to support the analysis. Missing or inappropriate information would weaken the estimates arrived at by accumulation of even the simplest impacts, and this weakness would be magnified for impacts estimated **by** aggregation. Each weak or missing estimate may threaten the utility of other estimates of cumulative impacts needed to achieve the goals of the study.

The Snohomish guidelines (Sec. 6.9) present some information requirements for cumulative effects assessments. The same variables and parameters should be measured throughout the geographic boundaries of the study area, and all direct and indirect single-project effects should be assessed consistently, using the same models or evaluative procedures.

Systematic application of a cumulative assessment methodology in the Columbia River Basin would be greatly facilitated by the development of a geographic information system and data base because such a system would provide consistency in the information used for various studies and reduce the costs and time necessary to re-collect data for each study. Data bases and geographic information systems developed for planning purposes may not be sufficiently detailed for cumulative impact assessment; however, the anadromous fish data base being compiled by the Northwest Power Planning Council and the Bonneville Power Administration includes data on river reaches that are potentially of great value for cumulative assessment. Argonne National Laboratory has developed a high-resolution mapping system to assist in cumulative impact assessment for the CIAP, but the system is not capable of incorporating quantitative and descriptive textual information. Further development of data bases and geographic information systems to assist in cumulative impact assessment is needed.

Participants in the assessment should be responsible for initiating data collection within their institutions or for securing outside help. If additional resources are necessary for the study, the list of participants should include individuals who can secure access to such resources.

7.2.4 Design of a Strategy for Aggregating and Accumulating Cumulative Effects

One of the first decisions that must be made in a cumulative effects study is to determine to what extent effects on the physical environment will bring about changes in biological populations. While some of the direct effects of hydroelectric development are on populations (e.g., mortality of smolts at turbines), many other effects are on the physical environment (e.g., changes in stream flow or gravel imbeddedness). These changes in the physical environment are important **because** they indirectly affect fish and wildlife populations. In order to assess any aggregated cumulative effect (i.e., the overall effect of a project on a species or the combined effect of several environmental changes on a species), assessments of effects on the physical environment must be transformed into assessments of effects on populations.

Either a univariate or multivariate modeling approach could be taken for aggregating the multiple effects of a single project. The way in which the population of a species responds to multiple effects will determine which approach is most appropriate for the cumulative assessment.

In some cases, populations respond to multiple environmental effects as if these effects occurred independently of each other. For example, the effect of sedimentation on salmonid emergence downstream of a project might act independently of the effect of inundation on salmon upstream of the same project. Often, however, populations do not respond independently to multiple effects. For example, the effect of sedimentation on emergence can be influenced by water temperature. When a hydroelectric project affects both sedimentation and water temperature, the species' response can be complex. Effects that do not act independently of each other are referred to as synergistic, if the response of the species to the two effects together is greater than if the effects occurred separately, or antagonistic, if the response of the species to the two effects is less than if the effects occurred separately. Such complex interactions should be considered during an assessment (see Sec. 5.2).

If effects that acted independently were the only ones being considered in the assessment (step A on Fig. 7.3), a univariate modeling approach could be used to aggregate the effects of each hydroelectric project. Using this approach, two univariate models -- one for the effect of sedimentation and one for the effect of inundation -- could be used to estimate the impacts on the population (step C) from the habitat effects assessed in step B. The output from these two models could be added together (if the output from the two models were in the same units) to arrive at the overall effect of each project on the population (step D). An accumulation method would have to be used (step E -- see Sec. 7.2.7) to arrive at the overall cumulative effect of multiple projects (step F).

If synergistic or antagonistic effects were being considered in an assessment (step A on Fig. 7.4), a multivariate modeling approach would be most appropriate for aggregating the effects of each project. This approach would require the use of a model that provided an estimate of the population's response to the complex interactions among effects (step C) and the output from this model would provide an estimate of the overall effect of each project on the population (step D). The method used to accumulate the effects of multiple projects (step E) to derive the overall cumulative effect (step F) could be the same as that used with the univariate approach.

7.2.5 Development of Models for Estimating Population Effects from Habitat Effects

Both of the approaches discussed in Sec. 7.2.4 rely on the use of models to quantify the habitat and population changes that result from hydroelectric development. These models are essential for an objective, scientific assessment of cumulative effect. Frequently, however, models that are appropriate for the species or regional population are not available (see Sec. 4). In these instances, a series of AEAM modeling exercises could be used to develop models for estimating effects on fish and wildlife from effects on habitats.

Development of models or other procedures for estimating habitat effects and population effects must be coordinated with the tasks of establishing information

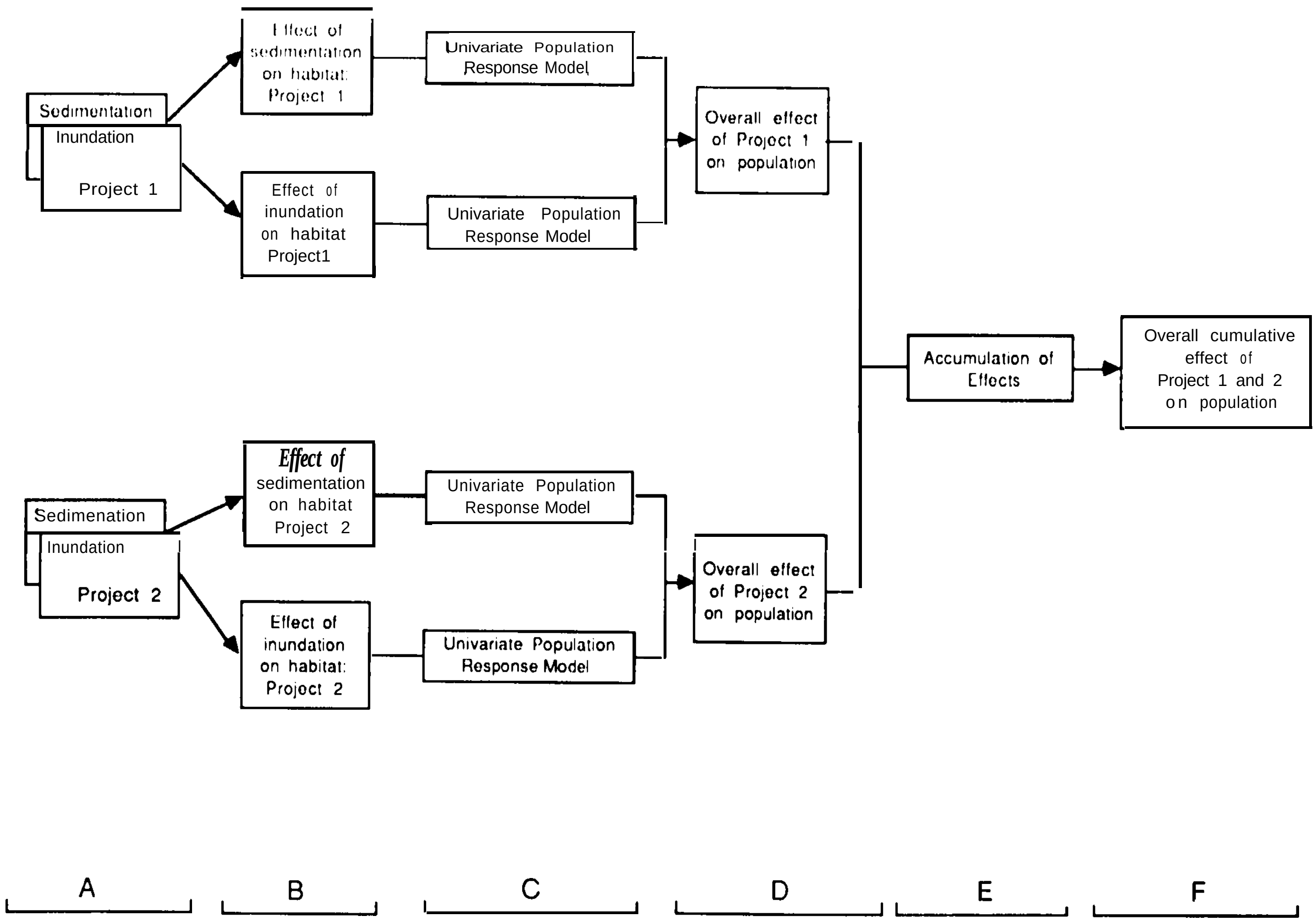


FIGURE 7.3 Univariate Modeling Approach for Evaluating Cumulative Effects

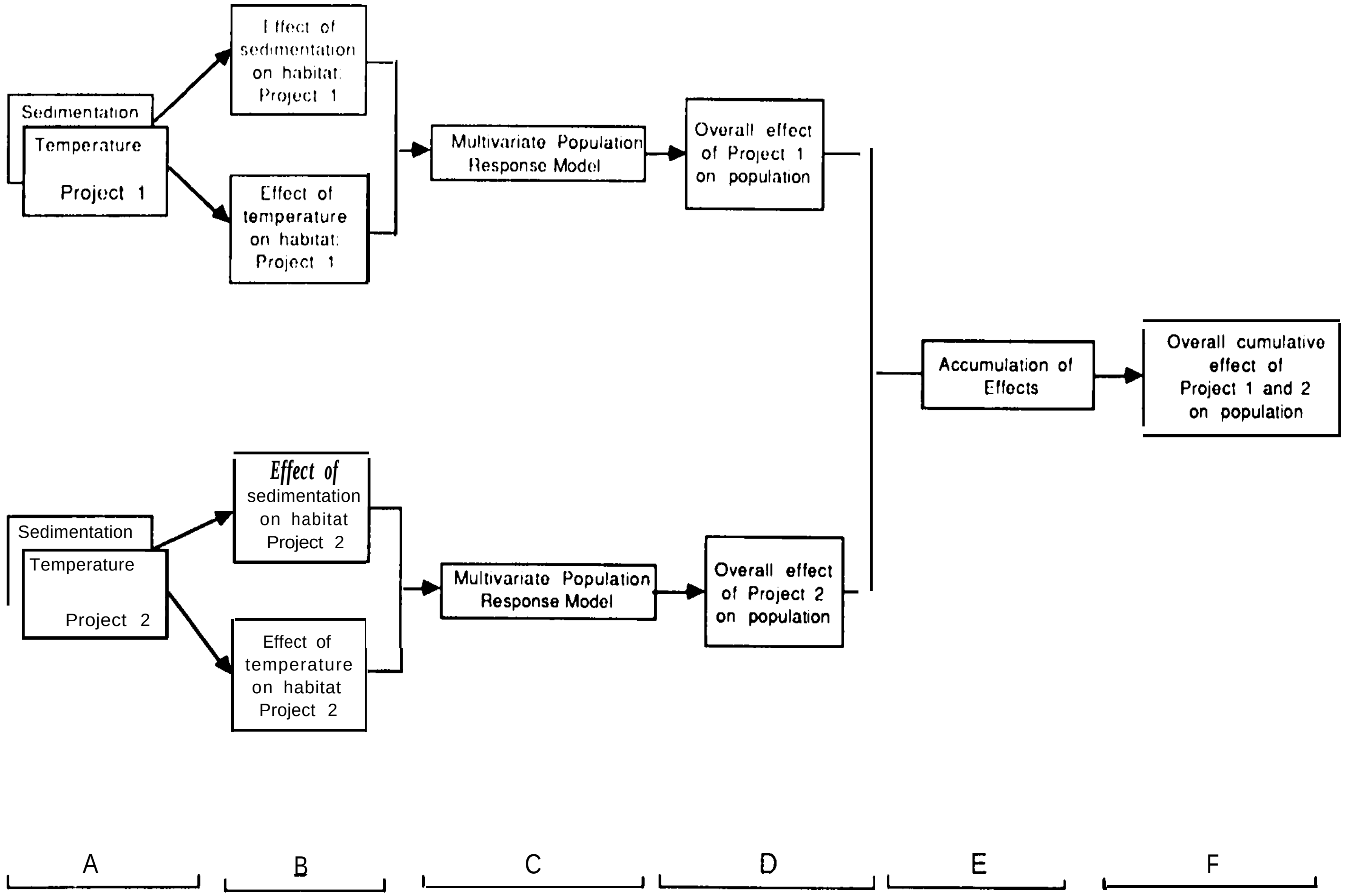


FIGURE 7.4 Multivariate Modeling Approach for Evaluating Cumulative Effects

requirements and developing a strategy for cumulative assessment. The order in which all of these tasks are accomplished is not important if coordination is an iterative process.

7.2.6 Information Collection and Single-Project Assessments

The ways in which information is collected and single-project assessments are performed will depend to a great extent on the decisions made during the tasks described above. Information collection and single-project assessments would be no different for cumulative than for noncumulative environmental assessments. It should be noted that all of the weaknesses in the data and in the single-project assessments would be carried over into the cumulative assessment, and some of the procedures for accumulating and aggregating effects will magnify the weaknesses and uncertainties in the data.

For ease of interpretation, we recommend that the effects of projects on various species or resources be expressed in units that directly reflect the magnitude of the effect (e.g., number of adult individuals lost, acres of habitat lost) rather than evaluative criteria. This will facilitate interpretation of the assessment and enable placing the results of the assessment in the context of established management goals.

7.2.7 Accumulation of Cumulative Effects

Tables, in the form of matrices, should be used to display the many values used in accumulating cumulative effects. Matrices are bivariate arrays, with one category forming columns and another category forming rows. At each cell where a column and a row intersect, some information on the characteristics of that row and column is placed. The mathematics of arrays, called matrix algebra, has been used extensively in population modeling, ecosystem modeling, and statistics. For cumulative impact assessments, few of the capabilities of matrix algebra beyond addition and multiplication are needed. However, matrices provide an excellent means of organizing and systematically presenting multidimensional data.

As described in Sec. 4, three types of cumulative impacts can be distinguished, based on the way in which multiple impacts affect a common resource. Additive effects from multiple projects on a single species are calculated simply by adding the effects of each project. With additive accumulation, one assumes that the effects are incremental and that no interactions occur among the effects that would enhance or diminish the cumulative effect. An example of an additive cumulative effect might be the total acreage of riparian habitat removed during construction of several separate small hydroelectric projects (see Fig. 7.5).

For effects measured in terms of biological responses to hydroelectric development, there is good reason to assume that multiple hydroelectric projects will produce effects that interact to enhance or diminish the additive effect. An example would be the effect of sedimentation changes on fish spawning success. This effect, like many of those associated with hydroelectric development (Sec. 3), is a complex, aggregate effect **that** incorporates both the direct effect of sedimentation and the

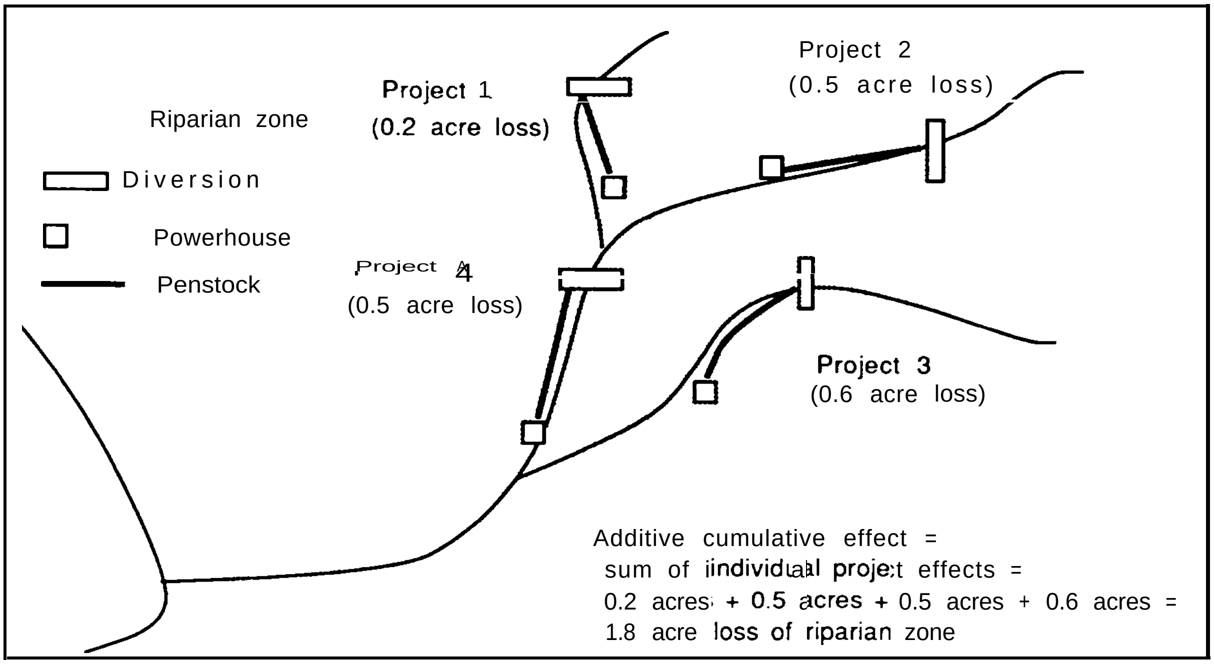
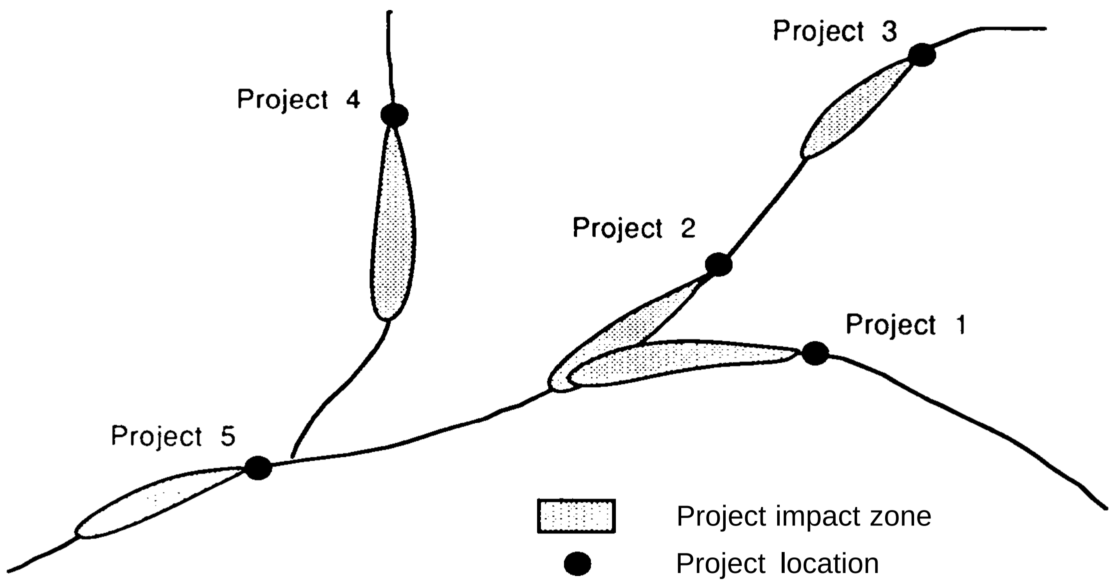


FIGURE 7.5 Example of an Additive Cumulative Effect

indirect effect of fish response to sediment. The calculation of supra-additive and infra-additive effects should take into account any interactions among projects that result in nonlinear biological responses. Matrices provide an excellent way to accomplish this task.

Figure 7.6 illustrates an example of nonadditive, interactive effects and the matrix calculation of these effects. The project-by-project interaction matrix shows, in each cell, the interaction between the project represented by the row and the project represented by the column. The value in each cell is zero if no interaction exists between the pairs of projects, positive if the interaction is supra-additive, and negative if the interaction is infra-additive. Ones make up the elements along the main diagonal. In the example in Fig. 7.6, only two projects interact. The presence of project 1 increases the impact of project 2 by 50% (0.5), and project 2 increases the impact of project 1 by 20% (0.2). None of the other projects interact.

The impact matrix in Fig. 7.6 contains the individual effects on each project alone, i.e., the single-project effects, in order to calculate the cumulative effect of all of the projects. This impact matrix has one row and as many columns as there are projects (Fig. 7.6). If nonadditive effects did not occur, the sum of the elements in the impact matrix would equal the cumulative effect of all projects. In order to account for interactions among projects, the interaction matrix and the impact matrix are multiplied using matrix algebra. That is, the first element of the impact matrix is multiplied by the element in the first row and first column of the interaction matrix; the second element of the impact matrix is multiplied by the element in the second row and first column; and so on until all of the elements of the impact matrix have been multiplied by the



Impact Matrix

Interaction Matrix

$$
\begin{array}{c}
\text{Project} \\
\begin{array}{ccccc} 1 & 2 & 3 & 4 & 5 \end{array} \\
\text{Impact } [5 \quad 10 \quad 12 \quad 50 \quad 20]
\end{array}
\times
\begin{array}{cc}
 & \text{Effect of project} \\
 & \begin{array}{ccccc} 1 & 2 & 3 & 4 & 5 \end{array} \\
\text{Project affected} \begin{array}{c} 1 \\ 2 \\ 3 \\ 4 \\ 5 \end{array} &
\left[\begin{array}{ccccc}
1 & 0.2 & 0 & 0 & 0 \\
0.5 & 1 & 0 & 0 & 0 \\
0 & 0 & 1 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 1
\end{array}\right]
\end{array}
$$

Product Matrix

$$
= \left[\begin{pmatrix} 5 \\ + \\ 5 \\ + \\ 0 \\ + \\ 0 \\ + \\ 0 \end{pmatrix}
\begin{pmatrix} 1 \\ + \\ 10 \\ + \\ 0 \\ + \\ 0 \\ + \\ 0 \end{pmatrix}
\begin{pmatrix} 0 \\ + \\ 0 \\ + \\ 12 \\ + \\ 0 \\ + \\ 0 \end{pmatrix}
\begin{pmatrix} 0 \\ + \\ 0 \\ + \\ 0 \\ + \\ 20 \\ + \\ 0 \end{pmatrix}
\begin{pmatrix} 0 \\ + \\ 0 \\ + \\ 0 \\ + \\ 0 \\ + \\ 50 \end{pmatrix} \right]
= [10 \quad 11 \quad 12 \quad 50 \quad 20]
$$

Cumulative effect = sum of elements in product matrix

$$= 10 + 11 + 12 + 20 + 50 = 103$$

FIGURE 7.6 Example of Matrix Calculation of Nonadditive Effects

corresponding elements of the first column of the interaction matrix. These products are summed to produce the first element of the product matrix. In a similar fashion, the elements of the impact matrix are multiplied by the elements of the remaining columns and the sums computed to produce the remaining elements of the product matrix. This product matrix will have the same dimensions as the impact matrix.

Only interactions between pairs of projects (first-order interactions) are used with the ITM. The use of first-order interaction term- enables the cumulative effect of many different development scenarios (combinations of different projects) to be evaluated. Projects can be selectively eliminated from the impact and interaction matrices and a new cumulative effect value calculated. The recommended method for calculating first-order interactions is discussed further in Volume 2 of this report.

7.2.8 Relationship of Cumulative Assessment to Planning and Regulation of Hydroelectric Development

The purpose of a cumulative effects assessment is to provide a better mechanism for incorporating fish and wildlife concerns into the planning, review, and authorization of hydroelectric development. Regulatory authority for construction and operation of hydroelectric facilities is the responsibility of the U.S. Army Corps of Engineers for Federal facilities and of FERC for non-Federal facilities. These agencies prepare environmental impact statements according to the regulations promulgated by the CEQ under the authority of NEPA. These regulations define cumulative effects (Sec. 5) and require that they be included in the analysis of individual projects.

In an environmental impact statement, cumulative effects should be evaluated for several scenarios with different combinations of existing and proposed projects. Thus, the cumulative effects methodology should have the capacity to estimate the cumulative effects not only of a proposed action, but also of various alternatives using equivalent data and procedures. In the methodology proposed here, the analysis of alternatives would be accomplished by iterative runs for accumulation and aggregation with different sets of input data. The estimates of cumulative impact would begin with an explicit statement of individual-project effects, the ways in which projects and effects interact, and the interaction coefficients. Any of these parameters may be changed and the cumulative effects recalculated.

The successful application of cumulative effects assessment in the Columbia River Basin as a result of this study would depend on a variety of other regulatory and planning activities conducted by the Northwest Power Planning Council (NWPPC); BPA; other Federal agencies, including the Corps of Engineers, FERC, the National Marine Fisheries Service, and the U.S. Fish and Wildlife Service; state agencies; Tribes; and the hydropower industry. These entities plan and manage the harvest, enhancement, and protection of fish and wildlife resources, and they maintain data bases and other sources of information on environmental conditions and fish and wildlife populations. Since the ITM is a data-intensive methodology, it cannot be applied without interagency cooperation such as is provided by the Hydropower Assessment Steering Committee of the NWPPC.

Current hydropower planning activities in the Columbia River Basin are closely related to the use of cumulative assessment. The hydropower site data base of the Corps of Engineers, the Pacific Northwest River studies, the fish losses and goals study, the hydropower option program of BPA, and the fish enhancement plans of agencies and Tribes will all be influential in the application of a cumulative effects assessment methodology. Recognizing the need for coordinated review of plans, the NWPPC has already used the AEAM methodology to develop an anadromous fish model for basinwide planning in the Columbia River Basin.

The Pacific Northwest river studies are to be used to develop a regional siting plan through the cooperating agencies, industry, and the Tribes. Through these studies seven data bases on natural resources are being concurrently developed: anadromous fish, resident fish, wildlife, natural features, cultural resources, recreation, and institutional constraints. These data bases will be essential for the successful application of cumulative effects assessment on a regional scale. Also, cumulative effects assessment would make an important contribution to a regional siting study, since an overall, basinwide perspective on the importance of incremental effects could be provided.

7.2.9 Conclusion

The ITM is recommended for cumulative effects assessment of hydroelectric development on fish and wildlife in the Columbia River Basin. The ITM approach has several advantages. It is very flexible and can be applied to many different types of projects, species, habitats, and assessment purposes. With it, impact and interaction information is displayed in a systematic and organized fashion that enables a quick determination of which projects have the greater single-project effects and which projects interact most strongly (and in which manner) with others. Reviews of the impact and interaction matrices can enable the analysis of different development scenarios as discussed in Sec. 7.2.7. Projects with large single-project impacts or strong interactive effects can be eliminated from the matrices and a new cumulative effect calculated. This can be done repeatedly to facilitate the regulatory and management decision-making process.

A disadvantage of the ITM is the need for more data than are currently available. These data are required to build the models needed for estimations of effects on resources. These models must be able to produce estimates of nonlinear effects and to incorporate synergistic and antagonistic relationships among variables. If those data and models are available, or can be collected or developed, the procedure allows flexibility in designing the scope of the study and provides an appropriate framework for analyzing a wide variety of development scenarios.

The ITM uses only first-order interactions (those between pairs of projects) to calculate the cumulative effect of multiple projects. Although higher-order interactions among projects may occur, the cost of accounting for these interactions, in terms of reduced flexibility, would be great. The incorporation of higher-order interactions would require the development of one simulation model that incorporated all of the single-project effects of all of the projects under consideration. Reliance on only first-order interactions allows evaluation of many different development scenarios without the development of new complex models.

With the ITM, a separate cumulative assessment would be done for each of the resources being considered in the assessment. The ITM does not provide an approach for aggregating into one value the overall cumulative effect on all resources. In order to do this, important decisions would have to be made among agencies as to how these impacts should be aggregated. These decisions would include determination of resource priorities and the development of some common unit of impact expression. Aggregation could mask important effects, however, and would likely reduce the utility of the assessment.

In summary, a recommended methodology is presented in this section for application to cumulative effects assessment of impacts on fish and wildlife by hydroelectric development in the Columbia River Basin (Table 7.2). The methodology consists of developing a matrix-based framework, with the assistance of AEAM negotiative procedures, for impact aggregation and accumulation. Other assessment techniques can be incorporated, such as evaluative and modeling procedures, to estimate impacts and systematize the accumulation and aggregation of data. This methodology is being recommended in order to provide a common ground for analysis of cumulative impacts by existing resource management institutions.

TABLE 7.2 Steps in the ITM for Cumulative Affects Assessment

Step	Methodology or Technique
Define the study scope	AEAM methodology
Establish cumulative assessment strategy	Habitat,environmental process, or population-oriented strategy
Establish information requirements	AEAM procedures for guidelines and data base
Develop models for assessing population effects from habitat effects	Existing assessment methods or AEAM methodology
Accumulate and aggregate data	Impact and interaction matrices
Participate in fish and wildlife management decisions	AEAM-type iterations for application and modification of matrix framework

7.3 REFERENCES

Alverson, D.L., and W.T. Pereyra. 1969. Demersal fish explorations in the northeastern Pacific Ocean: an evaluation of exploratory fish methods and analytical approaches to stock size and yield forecasts. Journal of the Fisheries Resources Board of Canada 26:1985-2001.

Beverton, R.J.H., and S.J. Holt. 1957. On the dynamics of exploited fish populations. U.K. Ministry of Agriculture and Fisheries, Fishery Investigations (Sec. 2) 19:533.

Chapman, D.G. 1973. Spawner/recruit models and estimation of the level of maximum sustainable catch. Rapports et Proces/verbaux des Reunions Conseil pour 1'International Exploration de la Mer 164:325-332.

Chapman, D., J.M. Van Hyning, and D.H. McKenzie. 1982. Alternative approaches to base run and compensation goals for Columbia River salmon and steelhead resources. Unpublished information.

Cushing, D.H. 1973. The dependence of recruitment on parent stock. Journal of the Fisheries Resources Board of Canada 30(12,2):1965-1976.

Gangmark, H.A. 1957. Fluctuations in abundance of Columbia River chinook salmon 1928-54. Special Scientific Report 189: Fisheries. U.S. Fish and Wildlife Service. 21 pp.

Horner, N., and T.C. Bjornn. 1981a. Status of upper Columbia and Snake River coho salmon in relation to the Endangered Species Act. Prepared by Idaho Cooperative Fishery Research Unit, University of Idaho, Moscow, for U.S. Fish and Wildlife Service. 45 pages.

Horner, N., and T.C. Bjornn. 1981b. Status of upper Columbia and Snake River spring chinook salmon in relation to the Endangered Species Act. prepared by Idaho Cooperative Fishery Research Unit, University of Idaho, Moscow, for U.S. Fish and Wildlife Service. 63 pages.

Horner, N., and T.C. Bjornn. 1981c. Status of upper Columbia and Snake River summer chinook salmon in relation to the Endangered Species Act. Prepared by Idaho Cooperative Fishery Research Unit, University of Idaho, Moscow, for U.S. Fish and Wildlife Service. 58 pages.

Irving, J.S., and T.C. Bjornn. 1981. Status of Snake River fall chinook salmon in relation to the Endangered Species Act. Prepared by Idaho Cooperative Fishery Research Unit, University of Idaho, Moscow, for U.S. Fish and Wildlife Service. 55 pages.

Junge, C.O., Jr. 1967. The effects of superimposed mortalities on reproduction curves. Resource Briefs. Oregon Fish Commission.

Junge, C.O., Jr. 1980. Techniques for assessing responsibility for passage losses at Columbia and Snake River dams. Unpublished information.

Junge, C.O., Jr. and A.L. Oakley. 1966. Trends in production rates for upper Columbia River runs of salmon and steelhead and possible effects of changes in turbidity. Oregon Fish Commission. Resource Briefs 12(1):22-43.

MacCall, D.C., K.R. Parker, R. Leithiser, and D. Jessee. 1983. Power plant impact assessment: a simple fishery production model approach. Fishery Bulletin 81(3). 7 pages.

MeCarl, B.A., and R.B. Rettig. 1983. Influence of hatchery smolt releases on adult salmon production and its variability. Canadian Journal of Fisheries and Aquatic Sciences 40:1880-1886.

Ricker, W.E. 1954. Stock and recruitment. Journal of the Fisheries Resource Board of Canada 11:559-623.

Ricker, W.E. 1958. Handbook of computations for biological statistics of fish populations. Bulletin 119. Fisheries Resources Board of Canada. 300 pages.

Ricker, W.E. 1975. Computation and interpretation of biological statistics of fish populations. Bulletin 191. Canadian department of the Environment, Fisheries, and Marine Service. Ottawa, Ontario.

Salo, E.A. and Q.J. Stober. 1977. Man's impact on the Columbia River stocks of salmon. Proceedings of Conference on Assessing the Effects of Power Plant-Induced Mortality on Fish Populations, 1977. Pergamon Press.

Thompson, D.H. 1945. The effects of the landslide at Hell's Gate on sockeye salmon in the Fraser River. Bulletin 1. International Pacific Salmon Commission.

Whitney, R.R. and R.S. White. 1984. Estimating losses caused by hydroelectric development and operation, and setting goals for the fish and wildlife program of the Northwest Power Planning Council: completion report. School of Fisheries, University of Washington.

8 SUMMARY

The Hydropower Assessment Steering Committee supplied initial lists of fish and wildlife species and habitats that are affected by hydroelectric development in the Columbia River Basin. After a review of the literature of hydropower effects on fish and wildlife, the species and habitat lists were revised to include 29 fish species and 39 wildlife species. The most important fish and wildlife habitats affected by hydropower development include streams, riparian zones, wetlands, and old-growth forests. The effects of constructing and operating hydropower facilities were reviewed from the extensive, but unconsolidated, literature on the subject. Hydropower effects on fish (nine categories) and wildlife (eight categories) were identified, described, documented, and categorized with regard to six hydropower development activities and the species affected.

Reviews and evaluations were conducted for (1) methods used to detect and quantify hydropower effects, (2) techniques used in impact assessment, and (3) methodologies potentially applicable to cumulative effects assessment. A large number and variety of analysis methods were reviewed for each category of hydropower development effects. These reviews emphasized methods currently being used in the Pacific Northwest to provide a background and foundation for developing and evaluating comprehensive assessment methodologies.

Environmental assessment methodologies are generally composed of several assessment techniques. Eight of the most common and useful assessment techniques were described so that comprehensive methodologies could be discussed with regard to them. Finally, 16 comprehensive methodologies were described and critically evaluated to determine which, if any, could be used to assess the cumulative effects of hydropower development in the Columbia River Basin. All of the 16 methodologies reviewed have different strengths and weaknesses, and no single methodology was found to be clearly superior or entirely adequate for use.

Cumulative effects assessment is a new and frequently confusing topic due to the lack of an established conceptual basis and terminology. To remedy this problem, Sec. 5 was devoted to defining the concepts and terms used in discussions of cumulative effects. The origins of cumulative effects were presented as the outcomes of interactions among multiple developments of one or more types. To be effective, a cumulative effects methodology must be capable of dealing with the relationships among multiple developments and effects.

Two new methodologies for cumulative effects assessment were developed in this report: stock/recruitment models and the integrated tabular methodology. The stock/recruitment methodology has been suggested by several investigators. While it is suitable for monitoring basinwide, long-term trends, it would be very difficult to implement for assessing new hydroelectric development and natural resource planning. The second new methodology, the integrated tabular methodology, is a flexible, matrix-based framework for analyzing the combined effects of multiple developments. This methodology is recommended for use in the Columbia River Basin and should provide a common ground for the analysis of cumulative effects from various types of development.